

DEVELOPMENT OF A COLD CORRUGATING PROCESS

**Project 2696-16
3331-12**

**Report Three
A Progress Report**

to

**THE FOURDRINIER KRAFT BOARD GROUP
OF THE**

AMERICAN PAPER INSTITUTE

and

MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

August 31, 1979

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

Over the period since the last progress report was issued, considerable work has been accomplished in each of the major aspects of the development of the cold corrugating process. The purpose of this report is to give a broad overview of this work and the results from it with subsequent reports to treat narrower fields in more detail. For organizational purposes, the report has been divided into four sections to treat adhesive development, forming process research, economic analysis, and pilot trials results. Salient results from each of these areas are summarized below.

PART I — ADHESIVE DEVELOPMENT

In accordance with the original plan, equipment for the on-line preparation of setback adhesives has been developed and is working satisfactorily. Such equipment is available in the pilot plant and in the laboratory as well. Commercial equipment has been specified on the basis of experience with these preparation systems.

Also in accordance with the original plan, physical and chemical characterization of a representative setback adhesive has been completed. Details of these analyses are presented in the report; however, the results did not prove of significant value in guiding adhesive development and so they will not be summarized here.

Rheologically, setback adhesives are shear-thinning but less so than conventional starch adhesives. The higher viscosity at the shear rates in the metering system nip results in thicker films on the transfer roll. In fact, film thickness has been shown to nearly equal the gap setting and to be quite insensitive to machine

speed and roll surface speed ratios. Because of the higher metering rate for a given gap setting and the lower film thickness required by higher solids level adhesives, it appears that gap settings of the order of 3 mils will be necessary to reduce starch application rates below 1.0 lb/M ft². This has been borne out by operating experience. Since 3 mils is not a practical gap value for commercial equipment, alternative metering equipment is being sought.

On the glue machine where a smooth doctor roll is used with a gravure glue roll, metering has been totally unsatisfactory. A trailing wiper blade working directly on the gravure roll has been added to the glue machine to essentially solve this problem.

Setback adhesives with bonding properties suitable for commercial operation of the single-facer have been available for some time with several different formulations meeting these requirements. Typically these formulas are ammonium persulfate, modified pearl cornstarch slurries that have been jet cooked and postadjusted in pH. Various additives are used both pre- and post. Until recently, however, most of the available adhesive formulations have developed bond strength on the double face side too slowly to permit satisfactory slitting at commercial speeds. To help in the development of adhesives with faster bonding rates, a double backer simulator has been developed to permit effective laboratory evaluation of double backing performance. With this device, adhesives with about 1% acrylic acid in the slurry have been shown superior to any previously evaluated formulation with respect to rate of bond development. A plant trial will be used to verify this performance.

PART II — FORMING PROCESS RESEARCH

Some additional work on identification of suitable medium treatment agents has been completed and has resulted in the selection of a mixture of 98% Shellwax 100 and 2% diethylphthalate as a satisfactory agent.

Evaluation of the geometric and structural properties of cold formed flutes shows calipers that are higher than for hot forming but draw factors that are comparable. Thus, for a given flute height, the cold process will use less medium. The potential fiber saving is significant but assessment of the economic value of this saving is pending more definitive tests and conclusion of the investigation of the lower flat crush for cold formed board. Corrugating rolls for cold corrugating will need a slight change in profile to give board calipers consistent with conventional operation.

A new roll deflector for mechanically controlling the take-off geometry of the single face web at the single facer has been designed, tested and shown to improve flute geometric consistency.

As a possible mechanism for minimizing flute fracture, a gear box to permit driving both corrugating rolls on the IPC single facer has been designed and a preliminary evaluation completed. This new gear drive can be adjusted so the bottom roll drives the top roll as in current practice, so the top roll drives the bottom roll, or at any intermediate point. The objective is to reduce the flank loads on the medium and hence the induced shear and tension loads. Preliminary evaluation of board properties and runnability has not revealed any influence from the dual drive regardless of the point of adjustment. A more definitive evaluation is planned.

Board produced by cold forming has lower crush resistance than that produced by hot forming. As an initial step in understanding the reasons for the difference

so corrective action can be taken, several investigative tools have been developed. These include use of load-deflection recordings in flat crush testing, video analysis of failures and measurement of flute geometry with the laser profilometer. At this point, these tools have shown that a geometric asymmetry develops in the cold formed flutes during flat crush evaluation. This appears to result from a low bending stiffness of the flute on one side near the tip. Work is continuing to more fully define this condition.

Recent data show that many corrugating mediums can be successfully cold formed without any form of pretreatment. This excellent cold runnability appears to be closely correlated to readily measurable medium properties thus suggesting that medium production processes can be adjusted to control runnability so that all mediums can be run without pretreatment.

PART III — ECONOMIC ANALYSIS

An analysis of the comparative economics of the hot and cold processes shows that the cold process will use 97% less process heat, 30-40% less electrical drive energy, and \$500,000 less equipment. In addition, the cold process will produce less warp and less waste, and will show higher production speeds on multiwall board. Maintenance costs and boiler room personnel costs will be lower as well. For a single corrugator, the savings in annual operating cost will be at least \$100,000 and could be two to three times that depending on local conditions.

PART IV — PILOT TRIALS

A 98-inch commercial corrugator at the Packaging Corporation of America plant in Burlington, Wisconsin, has been successfully converted to run with the cold process. This facility was designed to identify the problems of commercial operation of the cold process. It has now fulfilled that objective.

With the pilot facility, the 98 single-facer has been operated at commercial speeds to produce commercial quality board on several occasions. With formal design of a new single facer or a retrofit package, the single facing operation is ready for commercial use.

Combined board trials have produced board of commercial quality but not at commercial speeds as of this writing. Top speeds of 300-500 fpm have been achieved depending on the adhesive formulation in use. These speed limitations are the result of slitter edge delamination which, in turn, results from bond development rates that are too slow. Through the use of the double backer simulator, good progress is being made toward developing faster bonding adhesives and commercial speed traits are expected shortly.

Box compression data for boxes made via the cold process have been consistently excellent.

The basic purpose of the plant trials has been the identification of the problems of commercial application of the cold process. Based on the work completed to date, limited speed commercial operation is possible now. Full commercial production speeds will require a faster bonding adhesive for double backing. To achieve the full potential of the cold process, better adhesive metering systems will be required. Commercial operation in the near future appears as a very realistic goal.

INTRODUCTION :

For some time, exploratory work aimed at developing a cold corrugating process has been underway at The Institute of Paper Chemistry. Fundamental to this cold process is the cold forming of corrugating mediums, either by use of medium treatment agents or special forming processes, and bonding of the medium to the facings with a starch-based setback adhesive. Progress Report One, dated March 12, 1976, describes the results of a feasibility study of the cold process; Progress Report Two, dated February 3, 1977, describes the results of work to improve the adhesive for the cold process.

Results of these earlier projects were encouraging and led to the establishment of a comprehensive project to develop the cold corrugating process technology to the point of commercial reality. Since this development work requires both fundamental and applied work, a joint funding arrangement has been worked out whereby IPC supports the former and FKBG the latter. Expected to require about four years in total, this project is now about 60% complete thus dictating the issuance of this formal progress report. The work reported herein is covered in four parts: adhesive development, forming process development, economic analysis, and pilot trials.

PART I — ADHESIVE DEVELOPMENT

INTRODUCTION

Key to the success of the cold corrugation process is the development of an inexpensive adhesive compatible with a cold process and possessing all of the characteristics required of a corrugating adhesive. In pursuing this objective, aqueous, starch-based adhesives have the greatest potential for being cost competitive with conventional corrugating adhesives. For this reason, fundamental research to develop a suitable cold corrugating adhesive has been concentrated on starch-based materials. Significant work of an exploratory nature was discussed in Progress Reports One (dated 3-12-76) and Two (dated 2-3-77).

In this section, the procedures and equipment for preparing adhesive formulations presently used are described in some detail; the general physical, chemical and application characteristics of these adhesives are described; the bonding properties of the adhesive are presented; and preliminary results of ongoing exploratory work are reported. A more detailed report dealing only with adhesives is planned for later release.

PREPARATION OF ADHESIVES

Although numerous adhesive formulations have been used in the course of the development work, all have been prepared by procedures with essentially the same elements. These procedures involve chemical additions to a pearl cornstarch slurry, jet-cooking of that slurry and, finally, adjustment of the cooked starch to a final pH by the postaddition of 50% NaOH. One of the major early objectives in the cold corrugation project was the development of equipment suitable for these operations, namely, preparation of adhesives in a full-scale jet cooker and

the development of simple NaOH metering equipment. These steps, now completed, were necessary to provide adhesive preparation equipment for pilot trials and laboratory exploratory work and to provide a data base for the specification of cookers for commercial use. Descriptions of this equipment are given below. Adhesive handling equipment is described in Part IV, Pilot Trials.

For Project 3331-12, a jet cooker with sufficient capacity to supply the single-facer and double-backer in a commercial size machine has been developed. A schematic diagram of the cooker system is shown in Fig. 1. This system was constructed from a basic jet cooker supplied by Grain Processing Corporation (GPC) and suitably modified for this task. Several auxiliary items of equipment have been added to adapt the system to preparation of the set-back adhesive. A brief description of this system follows.

Several changes have been made on the original GPC cooker. Initially, the holding coil was comprised of 6 lengths of tubing giving a holding or cooking time of approximately 4-1/2 minutes. This has been changed to 6 half-lengths of tubing to reduce the holding time to 2-1/2 minutes and the cooker length by about 40%. A slurry mixing and holding tank, fitted with resettable flow and quantity meters to facilitate slurry preparation, has been added.

After jet cooking for about 2-1/2 minutes at 280°F, the final step in converting the starch slurry to an adhesive is the postcooking addition of NaOH to adjust the adhesive pH. NaOH is injected into the cooked starch by a metering pump after which the two components are thoroughly mixed in a static mixer. After passing from the mixer through the flash tank, the adhesive is collected in an overflowing catch basin, the overflow being directed to a waste receptacle or an adhesive holding tank. A pH cell in the catch basin monitors adhesive pH and, via

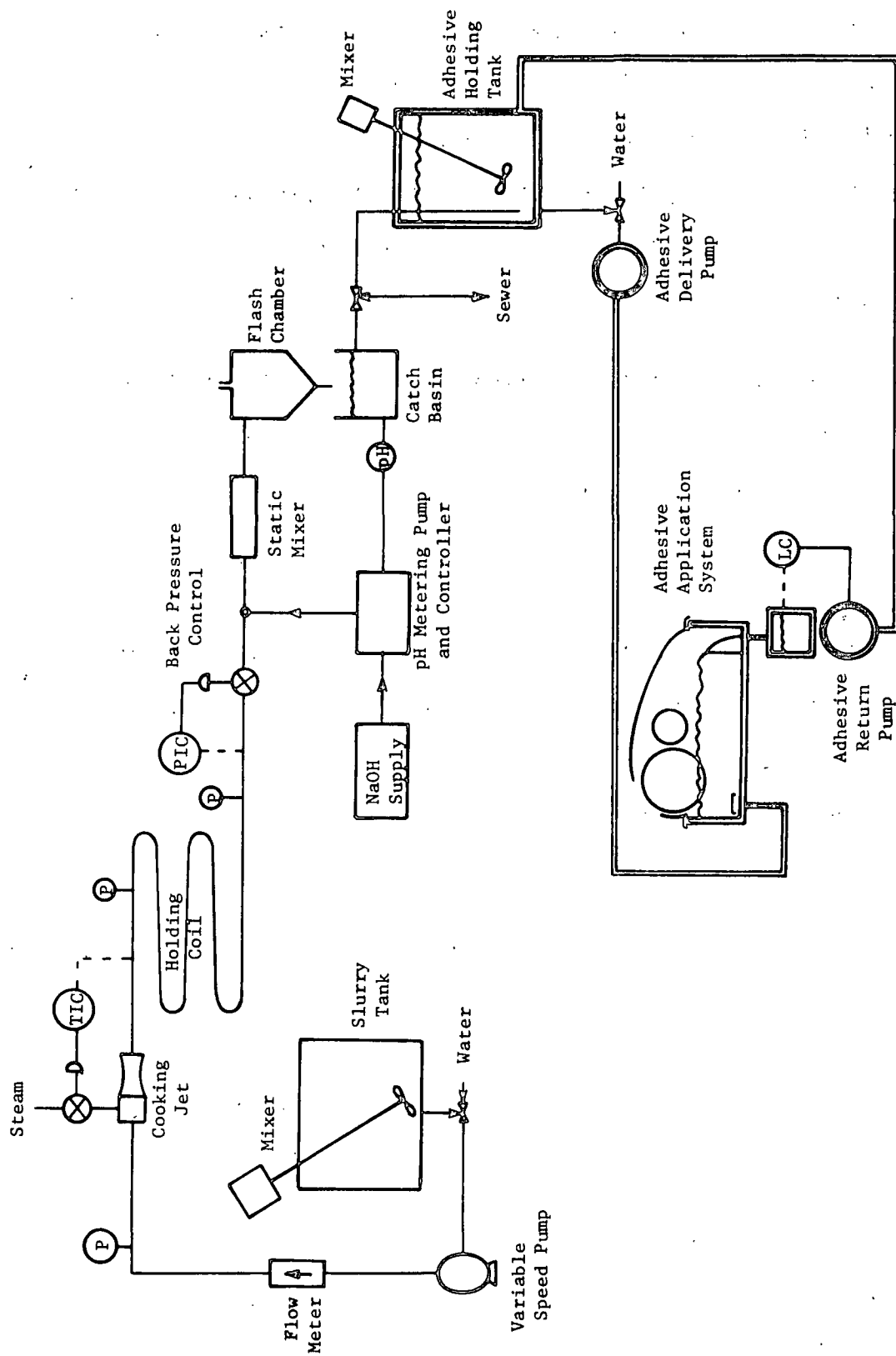


Figure 1. Schematic Diagram of Adhesive Makeup and Handling System

a transmitter and controller, adjusts the NaOH metering rate to control pH. The catch basin minimizes the time required to detect a change in pH resulting from a change in NaOH rate and thus eases the problem of control. In addition to the pH cell, several other instruments monitor various pressures and temperatures for recording on instruments on the cooker control panel. The cooker is enclosed within a cage for safety.

Except for startup and shutdown, the cooker is continuous and automatic and can operate with minimal attention until the need for adhesive is satisfied or the slurry supply has been exhausted.

PHYSICAL CHARACTERIZATION OF THE COLD CORRUGATING ADHESIVE

Cold corrugating adhesives are prepared by chemically modifying a pearl cornstarch slurry with ammonium persulfate. The modified slurry is jet cooked at about 290°F for about 150 seconds and then postadjusted to pH 9 with 50% NaOH. The resulting adhesive is held at a temperature of about 190°F until it is used.

The hot setback adhesive ready for use in the cold corrugating process is essentially a hydrosol containing amylose and amylopectin polymer fragments. Inorganic salts resulting from the decomposition of the chemical modifier ammonium persulfate (AP) as well as sodium hydroxide and reaction products from it may also be present in the finished adhesive. Other organic and inorganic additives may be included to selectively modify the behavior and performance of the adhesive.

For setback adhesives, the development of a green bond is due in part to the change from a hydrosol to a hydrogel by cooling from contact with the cold components. There may also be a contribution from the wet tack of the hot hydrosol

that is obtained even without cooling (and hence, thickening). Finally, bond strength increases as moisture is removed from the adhesive line.

Since both the bond formation processes and metering and application of setback adhesives depend critically on the physical characteristics of the adhesive material, these characteristics must be understood and controlled. The function, measurement, and importance of several key physical characteristics are described below. For convenience of reference, the list includes:

1. Adhesive solids content
2. Temperature
3. pH
4. Rheology/viscosity — gel temperature
5. Penetrating ability
6. Rate of formation of bonds
7. Cohesive strength
8. Molecular weight
9. Gel temperature

Adhesive Solids Content

Adhesive solids content is measured by carefully driving off all of the water and measuring the remaining solid material as a mass fraction of the original quantity of adhesive. Typically, adhesive makeup slurries are set at about 36% by trimming to an appropriate Baumé reading. Dilution by steam addition in the cooking process will normally drop the solids content to about 33% in the finished adhesive. These may be regarded as nominal values.

With respect to solids content several points need to be made. These are enumerated below.

- a. Whatever the solids content, the final bond is stronger and the adhesive more stable with time if all of the starch present in the slurry is cooked out or thinned in the conversion process.
- b. Final bond strength appears to increase slightly with solids content although it is difficult to isolate the effect of solids alone.
- c. Slurry solids levels of about 41% represent the upper limit for successful conversion in the jet cooker and this corresponds to a finished adhesive solids of about 38%.
- d. Higher total solids levels can be achieved by using slurry fillers such as clay.
- e. High solids levels lead to low amounts of water added during board manufacture, particularly if all the starch is dispersed to contribute to the bond. High solids levels also reduce the amount of material to be applied and thus challenge adhesive metering systems.
- f. It has been speculated that bond development rate is inversely related to solids content since the higher the solids the smaller the amount of water that must be removed to form a bond. This has not been proven but will be a subject of investigation with the double backer simulator, a new bond rate testing device discussed below.

Temperature

Setback adhesives emerge from the cooker at about 210°F and are allowed to cool to about 195°F. Cooling below this temperature results in a partially irreversible increase in adhesive viscosity and is thus to be avoided until bonding is desired. Figure 2 shows a representative viscosity-temperature cycle. From these curves, a drop in temperature of 18°C results in a 500 BU increase in viscosity but warming the adhesive back to the original temperature decreases the viscosity by only 230 BU.

From a bonding point of view, it would appear desirable to hold the adhesive at a temperature near the "gel point" as defined in Fig. 2. Doing so, however, greatly increases adhesive viscosity thus increasing the difficulty of pumping and metering. Furthermore, tests on the double backer simulator show no significant evidence that lowering temperature speeds up bonding. At this point, it is necessary to conclude that the adhesive temperature should be maintained near 190°F until the adhesive is applied to the flute tips. A $\pm 5^\circ\text{F}$ tolerance is currently recommended.

pH

Adhesive pH appears to be important in terms of adhesive stability, liner wetting and penetration, and bonding. For most past work, a pH of 9.0 has been deemed as proper. Some recent work suggests a lower value near 7.5 is better for some adhesive formulations.

To provide inherent liner wetting and hence to help formation rates for double face bonds, a pH of 11.5 to 12.0 is required. Unfortunately, pH values above 11.0 are nearly impossible to reach and cannot be maintained. Thus, this approach to liner wetting is not workable with setback adhesives.

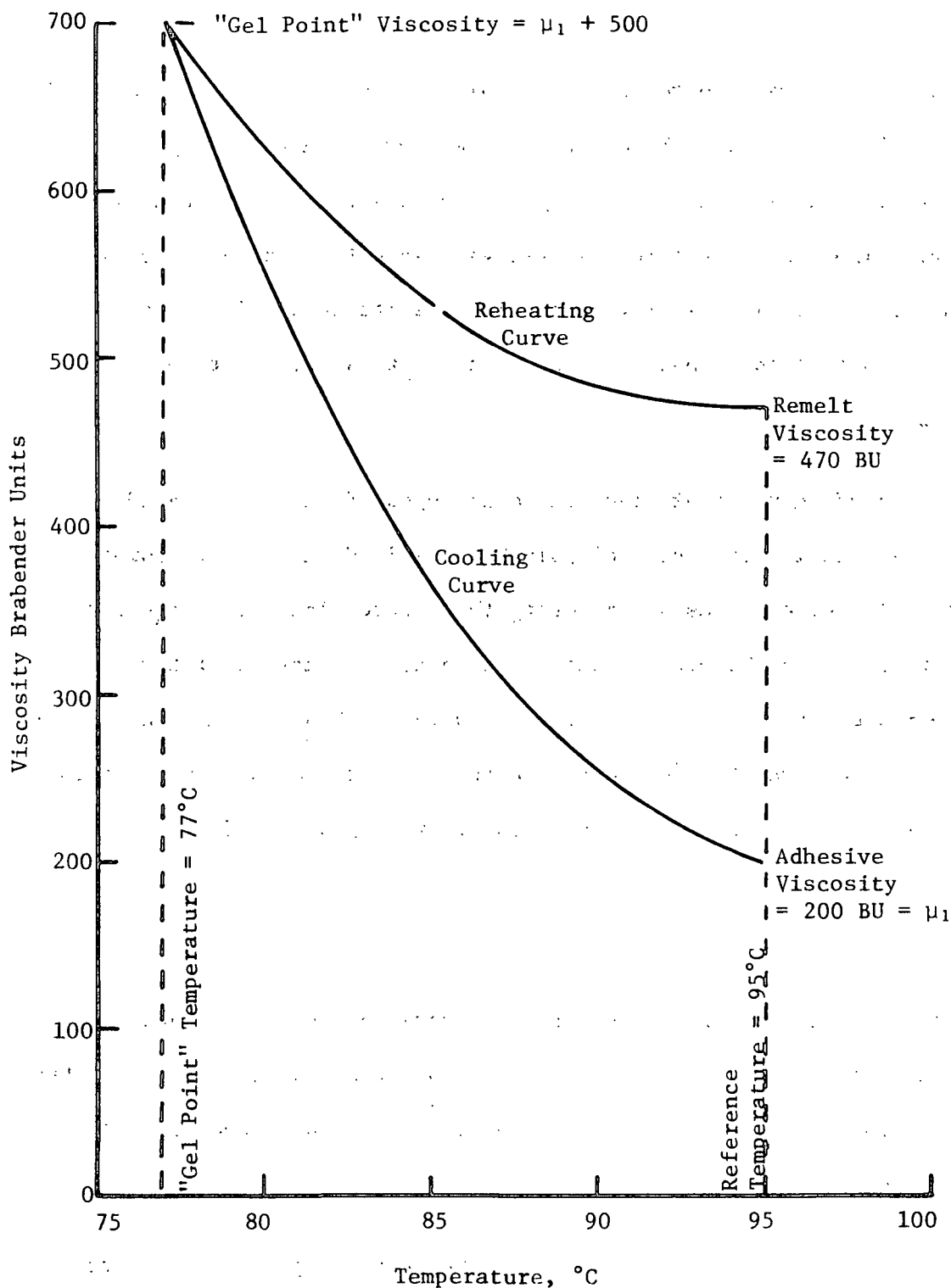


Figure 2. Adhesive Temperature-Viscosity Characteristics

Bond formation rates and final bond strength do not appear to be strong functions of pH over the range from 7.0-10.0. It has been discovered, however, that long-term stability of the stored adhesive is best if the pH is in the range from 7.5 to 9.0 so this has been selected as the target range. This has obvious implications for materials of construction for adhesive system components.

Rheology/viscosity

The Brabender Amylograph-Viscograph has been used extensively to evaluate the low shear rate viscosity and temperature-viscosity history of setback adhesives. Representative curves and definitions are given in Fig. 2. Viscosity, as measured in this way, is an important indicator of the degree of thinning of the starch polymer and thus as an indirect indicator of the effect of thinning agents and conversion conditions. In this way it serves as a useful tool in evolving adhesive formulations with desired properties.

Brabender viscosity is also important as an indicator of the ease with which a given material may be pumped and handled in an adhesive system. For adhesive systems presently in use, best handling performance is realized if the Brabender viscosity is less than 400 BU.

Setback adhesives are shear-thinning and show a 25-35% decrease in viscosity over the shear rate range from 0 to 20,000 sec^{-1} . By comparison, a conventional corrugating adhesive would show an 80% decrease over the same range. Thus, at the high-shear rate conditions encountered in the nip of two roll applicator systems, setback adhesives have at least twice the viscosity of conventional materials. This has an important impact on adhesive metering as discussed later.

Penetrating Ability

Penetrating ability is a measure of the depth to which starch from the setback adhesive migrates into the bonded components. It is usually measured by taper grinding or step grinding components after bonding is complete followed by iodine staining to determine the depth to which starch is resident. Good final bond strength is believed to require penetration of at least 0.002 inch; deeper penetration may actually be wasteful in terms of adhesive consumption. Fast bond development requires that the penetration occur rapidly to quickly disperse the water in the adhesive and also to quickly cool the adhesive. No technique for measuring penetration rate is presently known.

At the single facer, considerable pressure is applied during the combining operation. This results in significant mechanically induced penetration of the components with 0.004 inch being common and 0.008 inch occurring occasionally. From a final bond standpoint this penetration is not necessary. However, to develop a sufficient green bond in the short time available, it is necessary to use pressure roll loading values that result in deep penetration. It should be noted, however, that despite the deep penetration, most of the starch remains in the first 0.002 inch of the components.

At the double backer, combining pressures are too low to mechanically induce penetration. Hence only the naturally occurring gradients are available to move the starch. Typically, penetration is about 0.002 inch but nothing is known of the penetration rate. Because of the low pressure combining condition, the double facing bond formation rate may be slower than that on the single face side. This implies the need to select the adhesive and the combining conditions to optimize bond development rates.

Bond Formation Rates

Satisfactory production of combined board at high speeds requires an adhesive that forms a strong fiber-tearing bond in a short time so the board will withstand the rigors of slitting, scoring and cutoff. At a production speed of 600 fpm with present machine lengths, only about 8 seconds are available for the bond to form. The objective then, in adhesive development, is to produce a formulation that will set, under double backing conditions, to a strong fiber tearing bond in 8 seconds or less.

Early development work was based on use of the pilot facility at PCA, Burlington, or a simple and subjective bench test to evaluate bond development rate. In the latter test, a thin film of adhesive is drawn down on a temperature controlled plate, a single face sample is contacted with the plate to apply adhesive to the flute tips, and then the sample is combined with a double face liner. After 8 seconds, the bond is separated and the bond site inspected for fiber tear. Neither pilot trials nor the bench test provide enough control over the experiment or precision in the bond evaluation to permit effective comparison and optimization of adhesives. Because of this, a sophisticated double backer simulator has been developed and will be used in future work. Briefly, this device permits formation of bonds under carefully controlled conditions that duplicate double backing. It also permits evaluation of bond strength as a function of bond age and thus serves as an effective tool in adhesive development. A more complete description of this instrument is given in a later section.

Cohesive Strength of the Adhesive Polymer

In order that adhesive joint failure during testing or commercial industrial use not take place within the film of adhesive joining the adherends,

the substance comprising the adhesive must have a minimum cohesive strength exceeding the strengths of the adhesive/adhered interface or the strength of the adherend substances.

In the early work with cold corrugating adhesives containing only AP-modified starches, the adhesive failure locus was frequently within the adhesive layer, particularly at low solids. As improvements in preparation and formulation, even at low solids, took place the locus of failure changed to adherend/adhesive interface or within the medium. With most recent adhesives the locus of failure is rarely at an interface, but more usually within the medium, and even fairly frequently within the liner. The conclusion to be drawn is that current adhesive formulations have adequate cohesive strength in the adhesive polymers.

Molecular Weight of the Adhesive Polymer

A wide variety of techniques and procedures is available for determining the molecular weight of the starchy adhesive polymer. The method used in this work is to calculate the polymer molecular weight by using the intrinsic viscosity fitted into the following equation:

$$[\eta] = K \cdot M^a$$

where $[\eta]$ is the intrinsic viscosity, M is the molecular weight, and K and a are parameters whose values are taken from other work and methods for determining starch (or amylose or amylopectin) molecular weights.

The intrinsic viscosity $[\eta]$ is defined by the relation

$$[\eta] = \lim_{c \rightarrow 0} (\eta_{sp}/c) = \lim_{c \rightarrow 0} (\eta_k - 1/c) = \lim_{c \rightarrow 0} [(\eta/\eta_0 - 1)/c]$$

where η_k is the relative viscosity

η_{sp} is the specific viscosity

η_0 and η the viscosities of the pure solvent and polymer solution, respectively, at concentration c . $[\eta]$ usually has units of cubic centimeters per gram.

Wolff, Gundrum, and Rist developed a simplified procedure by which the relative viscosities (η_k) are measured by the time of flow of a 0.2% solution of adhesive solids dissolved in 1N KOH in a calibrated No. 100 Ostwald-Cannon-Fenske viscometer maintained at $25.10 \pm 0.03^\circ\text{C}$ in a thermostated bath. Present adhesive polymers require a No. 50 viscometer to give long enough flow times to yield adequate precision in the determinations. Using the equation

$$M = \frac{162\eta}{1.67 \times 10^{-3}}$$

the weight average molecular weights for several setback adhesive polymers have been found to range from 30,000 to 70,000.

A list of molecular weights of several polymers best suited for good adhesive action is shown below: [Reference (1), J. P. Casey].

Product	Mol. Wt. Range
Polyvinyl acetate	1,720-17,200
Polyethylacrylate	8,000-15,000
Polyisobutylene	2,800-8,400
Polyamides	12,900-25,800
Cellulose nitrate	51,750-103,500

Thus, the setback cold corrugating adhesive seems to be of a suitable order of molecular size.

Gel Temperature

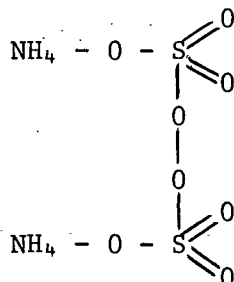
This is an arbitrarily chosen term defined as the temperature at which (upon cooling under the 1.5°C per minute rate of decrease of temperature in the Brabender Amylograph-Viscograph from 95°C at a stirring rate of 190 rpm) the Brabender Unit viscosity has increased by 500 units (875 cps), Fig. 2. Obviously the higher the gel temperature the more rapid is the cooking induced thickening or setting of the adhesive.

CHEMICAL CHARACTERIZATION OF THE COLD CORRUGATING ADHESIVE

Chemical literature references on the effect of ammonium persulfate as a viscosity-reducing reagent for starch hydrosols, combined with other references on the effects of a hot alkaline environment on starches, lead to the expectation that certain chemical changes occur in the starch polymer structure and configuration. These can be best discerned by a chemical characterization of the corrugating adhesive.

Conversion Chemistry

The cold corrugating adhesive is a hydrosol of a mixture of amylose and amylopectin, each reduced in molecular weight from the level it had as a component of unmodified corn pearl starch. These components are chemically altered by the combined acid hydrolysis during the cooking phase (pH levels of cooked paste are around 2.5 to 3.0), oxidative alteration due to the peroxidic structure of ammonium persulfate (AP), structurally depicted as



and the combined action of the hot alkaline environment on unaltered glucose units and/or already oxidized glucose units.

Carboxyl Groups

Spot-test reactions with methylene blue dye on dried particles of the cold corrugating adhesive show little or no carboxyl (-COOH) groups to be present. This observation is in line with literature references which state that persulfate oxidations of carbohydrate produce little or no carboxyl groupings (1).

Reducing Value/Aldehyde Groups

Aldehyde (-CHO) groups are produced at each site where the starch polymer chain is cleaved by acid hydrolysis. Since aldehyde groups are reducing agents one can get a measure of the amount of polymer cleavage by measuring the reducing value of the adhesive. A sample of adhesive cooked at 140°C (284°F) with 0.3% AP, with a 90-second holding time, was analyzed for reducing value and found to have a value equivalent to 4.4% glucose by Taylor, Fletcher, and Adams initial reducing value determination (2).

The above reducing value is at first glance surprisingly low in view of the fact that the starch has been in an acidic environment (pH about 2.5-3.0) at a temperature of 140°C (284°F) for 90 seconds. However, in addition to causing polymer cleavage, the acid environment can catalyze reactions of the aldehyde reducing groups with other portions of the adhesive so that the final amount of aldehyde grouping is lowered. One such reaction is the formation of acetals, $\text{R}_1\text{-CH(OR}_2)_2$, which are resistant to hydrolysis in the final alkaline environment, thus lowering the final aldehyde content.

Postcooking Conversion

In addition to the changes in molecular size and chemical structure which take place during the acidic 90-second cooking phase of the adhesive preparation, there are further changes induced by the final hot alkaline environment. It has previously been noticed that the pH drops during extended holding at 190°F (3), which indicates that acidic products are being formed by the action of the hot alkali on the adhesive.

The specific nature of the reactions taking place in the hot alkaline corrugating adhesive is unknown. There are a great number of references in the literature covering alkaline degradation of carbohydrates such as cellulose and starch (4,5,6-15) but they are of doubtful value in devising improvements in our cold corrugating adhesive.

Iodine Affinity

The iodine affinity of starch is a measurement of the binding of iodine by a solution of starch into a complex with the amylose component of starch (16). By conducting a potentiometric titration of a starch solution with 0.001N iodine solution one can determine the iodine affinity which for the amylose component of unmodified cornstarch is 189 mg/gram. For unmodified cornstarch the amylose content is 27%, so that one would expect to have an iodine affinity equal to 189×0.27 or 51.03. The iodine affinity of a sample of cold corrugating adhesive was 32.0 which represents a reduction of 37.2% in iodine binding capacity. This reduction in the ability of the amylose portion present in the starting cornstarch to assume the helical configuration required to bind iodine must be caused by changes in the chemical structure of the starch during the AP oxidation and subsequent hot alkaline environment holding. The exact nature of the changes is not known for this particular circumstance.

APPLICATION CHARACTERISTICS OF ADHESIVES

Conventional corrugators usually utilize a two roll adhesive applicator for both the single-facers and the glue machine. At the single-facer, two counter-rotating smooth rolls are typical; at the glue machine, a smooth doctor roll and a gravure transfer roll are normally used. Since these systems are so common in existing machines, the desirability of their continued use with setback adhesives for the cold process is evident. The objective, of course, is to use these systems within their normal operating range and to achieve satisfactory rates, uniformity, and controllability of adhesive application. Setback adhesives do, however, have rheological characteristics which differ from those of conventional adhesives in a way that is significant to metering. In this section, the rheological characteristics of setback adhesives will be explored; the significance of this from a metering point-of-view will be explained. Actual operating experience with conventional applicator systems and setback adhesives will be described and, finally, the implications of the properties of setback adhesives in terms of applicator system design will be outlined.

Metering Processes

Adhesive application is a two stage process in which a thin film of adhesive is metered onto a transfer roll which, in turn, comes in contact with the medium flute tips to transfer adhesive to them. If the assumption is made — and it seems to be supported by experience — that the amount of adhesive applied is directly related to the amount on the transfer roll, then effective control of application rate can be achieved by effective control of metering. With either of the two systems in dominant use, metering is accomplished in the nip between the two counter-rotating rolls.

In an exhaustive study of the subject metering process (albeit for smooth rolls only) Jurewicz (17) established the essentials of the relationship between the metered amount and the system parameters. Film thickness was found to vary directly with metering gap and in somewhat more complicated ways with surface speed ratios of the two rolls, operating speed, and the high-shear viscosity of the metered fluid. It was further discovered that for a fluid with a given high-shear viscosity, there is a roll surface speed ratio at which film thickness is independent of operating speed. This, in turn, implies an adhesive application rate that is independent of machine speed and that can be readily and directly controlled by gap adjustments.

Based on these findings, Jurewicz recommended that the high-shear viscosity of corrugating adhesives be monitored continuously, that the speed ratio be set to the corresponding critical value, and that application be controlled by gap setting. For conventional adhesives, the high-shear viscosity is around 15 cp, the corresponding M/A is about 0.9, and gaps of the order of 6-10 mils would be required.

Setback adhesives have rheological properties that are qualitatively similar to conventional adhesives (shear-thinning) but, quantitatively, the setback adhesives have much higher high-shear viscosities. Applying the above reasoning, this leads to critical speed ratios of around 0.1 and operating gaps of perhaps 3-5 mils for satisfactory metering. This is not readily achievable in a commercial operation thus suggesting a change to a different metering system.

The dynamics of metering against gravure rolls have not been studied but these and other problems are believed to be present there as well.

Operating Experience

The IPC pilot single-facer has a two roll applicator system with speed ratios variable down to 0.35. On the PCA commercial corrugator, the two roll applicator system is geometrically similar but the speed ratio is fixed at 0.8. Both operate with gaps as low as 5 mils but this is probably below the practical limit for commercial operation of the wide machine. Minimum achievable application rates for the 12-inch machine ($M/A = 0.35$) range around 1.0-1.2 pounds/M ft² whereas those for the wide machine ($M/A = 0.8$) are always above 1.5 pounds/M ft². Thus both are too high but the higher M/A definitely contributes to thicker films and more adhesive on the flute tips.

At the glue machine, metering is normally accomplished by a smooth, chrome-plated doctor roll working with a gravure roll with 16 cells/inch. Each cell is 0.018-inch deep. For setback adhesives, this system gives completely unsatisfactory metering. At gaps above about 6 mils, the transfer roll carries a thick layer of adhesive and transfers far too much to the flute tips. At gaps below about 5 mils, the gravure roll is stripped of all transferable adhesive so none is transferred to the flute tips. It thus appears that a smooth roll-gravure roll system is not workable with setback adhesives.

After experiencing difficulty with the standard commercial metering systems, some simple experiments in the plant and in the laboratory led to the conclusion that a trailing wiper blade would provide better metering. Accordingly, a trailing wiper blade system was designed for the commercial glue unit. This blade is flexible, mounted on structure heated by circulating hot water, mechanically adjustable for loading against the roll and has a full length air tube for air loading. The latter feature is used to insure uniform contact with the roll and to control, to some extent, adhesive application. The complete

assembly is designed for removal from the glue unit to revert to normal production.

A sketch of this apparatus is shown in Fig. 3.

To operate the blade system, the doctor roll gap is adjusted to a fairly large value to give a heavy coating on the transfer roll. This coating is then metered off by the blade to give the desired coating level.

With the simple wiper blade as described above and represented in Fig. 3, a near satisfactory metering level has been achieved. Some combined board of good quality has been made with a double face starch consumption rate of 1.0-1.2 pounds/M ft². Because of the simplicity of the blade design necessitated by reinstallation at each run, adjustment to achieve the lowest consumption level is difficult and tedious but the system is workable for these trials and has demonstrated the feasibility of the blade-roll system. Laboratory experiments under controlled conditions as well as some study of the theoretical basis for this type of metering process are required to establish optimum values for such design parameters as cell geometry, blade geometry, etc. Furthermore, for commercial application of this type of metering system, some mechanism for varying the metered amount over a reasonable range must be found.

ADHESIVE BONDING CHARACTERISTICS

In previous sections of this report the physical, chemical and application characteristics of setback adhesives have been described. None of these characteristics has any relevance, however, unless the bonding properties of the adhesives are acceptable. Bonding strength must be viewed in terms of the time rate of bond development, the ultimate strength of the bond, the locus of bond failure, and the stability of these characteristics with age and environment. These characteristics must also be sufficiently insensitive to component properties to permit successful bonding for

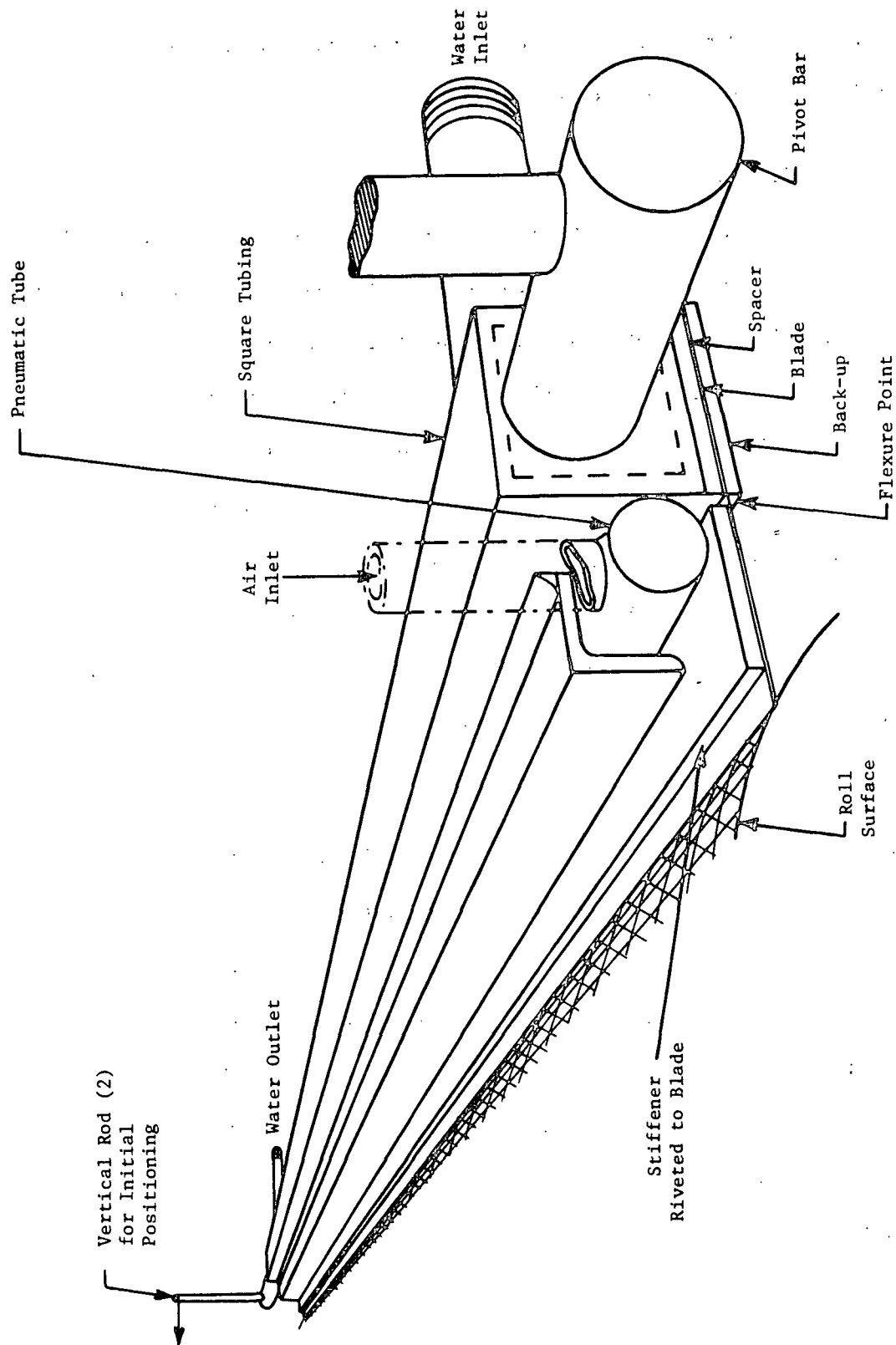


Figure 3. Wiper Blade Used on Glue Machine Gravure Roll

the normal range of roll stock variations. The purpose of this section is to present the bonding properties of various setback adhesives and to point out areas where further improvements are needed.

Final Bond Strength

Final bond strength is a measure of the force required to disrupt the bond joining the medium and liner. For a good adhesive this strength will be at least 4 lb/lineal inch of flute and the bond will fail by pulling fiber from the medium or the liner. If the bond fails by pulling fiber, then the cohesive strength of the adhesive is greater than the strength of one or more of the components and the adhesive has penetrated sufficiently to provide maximum bond strength. Both are important properties. Failure in the adhesive, i.e., without pulling fiber, implies that the adhesive is the weakest link in the bonding system. Final bond strength is typically evaluated by a standard pin adhesion test or by testing mature bonds on the double backer simulator discussed later.

Many different setback adhesive formulas have been evaluated with most giving excellent final bond strength, usually at least 5 lb/lineal inch. A few have been on the brittle side with a consequent adhesive failure rather than a fiber failure. Bond strengths are usually nearly the same for single face and double face bonds. At bond failure, fiber is almost always pulled from one component or the other with medium fiber failure being the more common. Suffice it to say that many setback adhesive formulas can be desired that give strong, fiber pulling final bonds for either single facing or double facing use. Required application rates will be discussed below.

Bond Development Rates

Adhesives suitable for corrugating must develop nearly full bond strength in a very short period of time so the freshly manufactured board has sufficient strength to withstand subsequent processing operations, particularly slitting, scoring and stacking. In hot corrugating, bond development results from heat-induced gelatinization and drying of the adhesive, a process that occurs under large heat transfer gradients imposed externally by the hot plate section. Set-back adhesives develop bond strength through loss of heat and moisture, but in the cold process, particularly in the double backer, these transport processes cannot be forced externally and thus must occur under natural gradients. To achieve satisfactory bond development rates under these conditions, it is necessary to minimize the amount of cooling and drying required to form a bond while simultaneously maximizing the transport rates.

Machinery set up for the normal production of corrugated board is poorly suited to the evaluation of bond development rates. In the pilot facility at PCA, Burlington, for example, it is possible to observe whether the bonds are sufficiently strong to withstand slitting and scoring under given operating conditions. It is not possible, however, to determine quantitatively the strength of the green bond nor is it possible to determine anything about the bond before or after the slitting point. In short, such facilities are expensive, work under poorly controlled conditions and yield little useful information for absolute or comparative evaluation of adhesives. These factors, coupled with the difficulty of achieving satisfactory bonding rates under the imposed conditions, led to the development of a double backer simulator as an adhesive development tool. A description of the simulator is given below followed by more specific information on the bond development rates of setback adhesives.

Double Backer Simulator

The Double Backer Simulator was designed to provide a controlled, easily repeatable test for the relative evaluation of cold corrugating adhesives. It was decided to model the full-scale double backing process as closely as possible in order to assign some meaning to the test variables and test results. Time was chosen as the primary test variable since it is the time for bond setup that is the most critical parameter in a successful corrugating adhesive. A 2-inch wide by 12-inch long strip of single face board is bonded to a double face liner in the simulator and the bonds are then broken one-at-a-time to create a measure of bond strength vs. time of bond existence.

For proper simulation, the total time interval for the double backing process was divided into three segments: open time, or the time between glue application to the flute tips and the point where single face board and double face liner are joined; time under pressure, where the finished board is under the double backer belt; and the total bond time from formation until the finished board reaches the slitter-scorer. Since a running speed of 600 fpm could not easily be achieved in a laboratory instrument, the simulation of these three time segments had to be accomplished by proper scaling of the machine size to its own operating speed and by providing additional time controls.

The machine was designed to be modular in nature. The major elements can be seen in the overall view of Fig. 4. The machine frame houses a hot water system for temperature control (lower left), liner sample roll (lower center) and air control system (lower right). The top of the frame supports a jacketed adhesive pan and applicator system (left center), an air loaded combining section (center) and liner pull rolls (right center). Immediately below the liner pull rolls is a load cell system for measuring the bond strength. The single face sample rides in

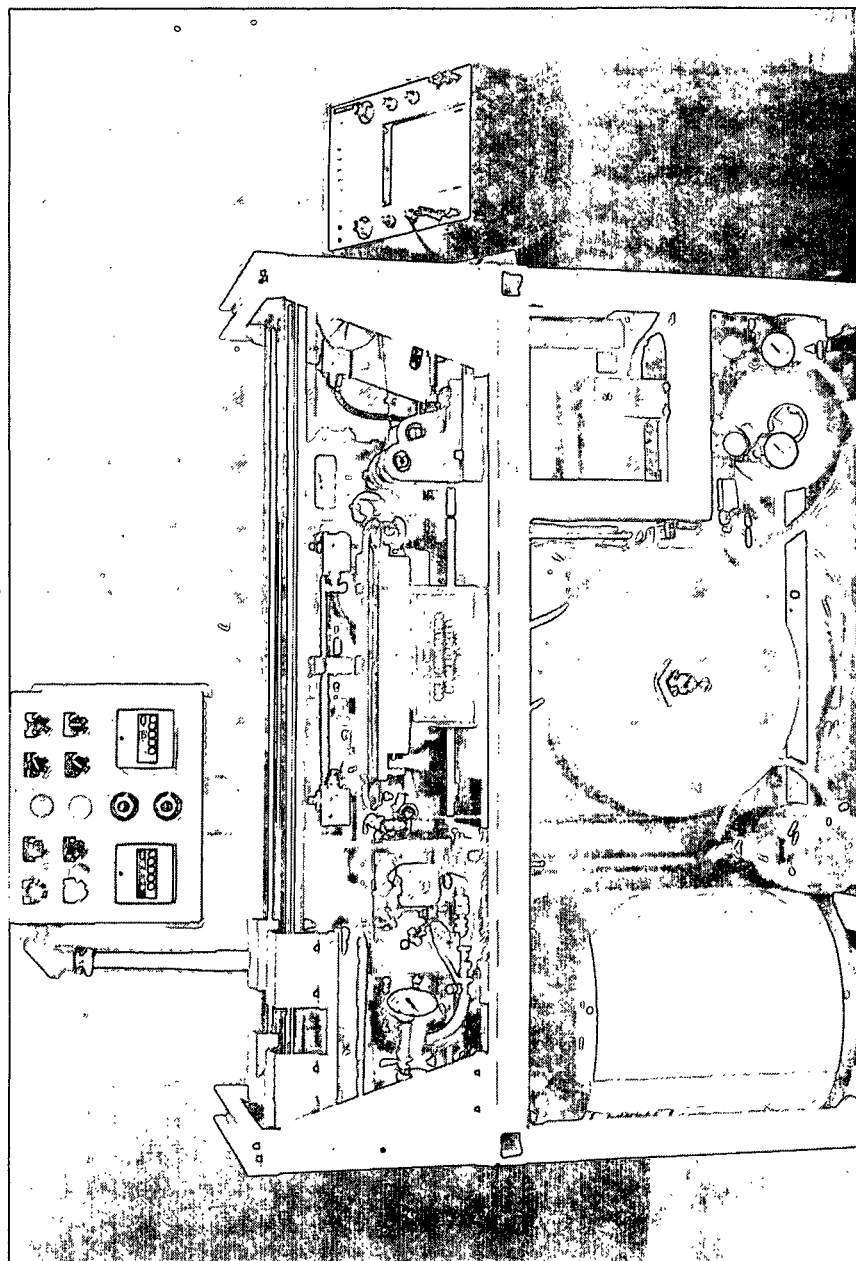


Figure 4. Overall View of Double Backer Simulator

a carriage (upper left) supported by horizontal rods across the top of the machine. Also seen in Fig. 4 is the electrical control panel (above the machine) and the bond force recorder (extreme right).

The machine was designed to be portable. It rolls on casters and is compact enough to be transported in a van. Only air and electrical connections are required for operation.

For a test determination, the 2 x 12 inch single face samples are cut with the 12-inch dimension in the machine direction. This provides about 39 flutes for individual bond strength determinations. The single face liner of the same is bonded to a metal holder with two-sided tape. The holder with sample is slipped into the end of the sample carriage with the flute tips down and clamped in place with compression springs. The adhesive pan is prewarmed to the desired temperature by the hot water system and filled with adhesive. The desired adhesive film thickness is set on the adhesive pan applicator roll by adjusting the position of a single doctor blade. The applicator roll turns continuously at an idle speed. The double face liner is threaded from its supply roll over the air table combining section, down and under the roll on the load cell and then up to the pull roll and through the pull roll nip. A weight is attached to the liner near the supply roll to provide the liner with a controlled amount of tension.

At the start of a test cycle, the sample carriage begins to move across the top of the machine (left to right in Fig. 4) at a preset speed and the flute tips contact the glue roll to pick up adhesive. This speed determines the open time between point of glue application and contact with the double face liner. The positional relationship between adhesive pan and liner can be seen in Fig. 5. At the start of the test, a set of clutches disengages the glue applicator roll from

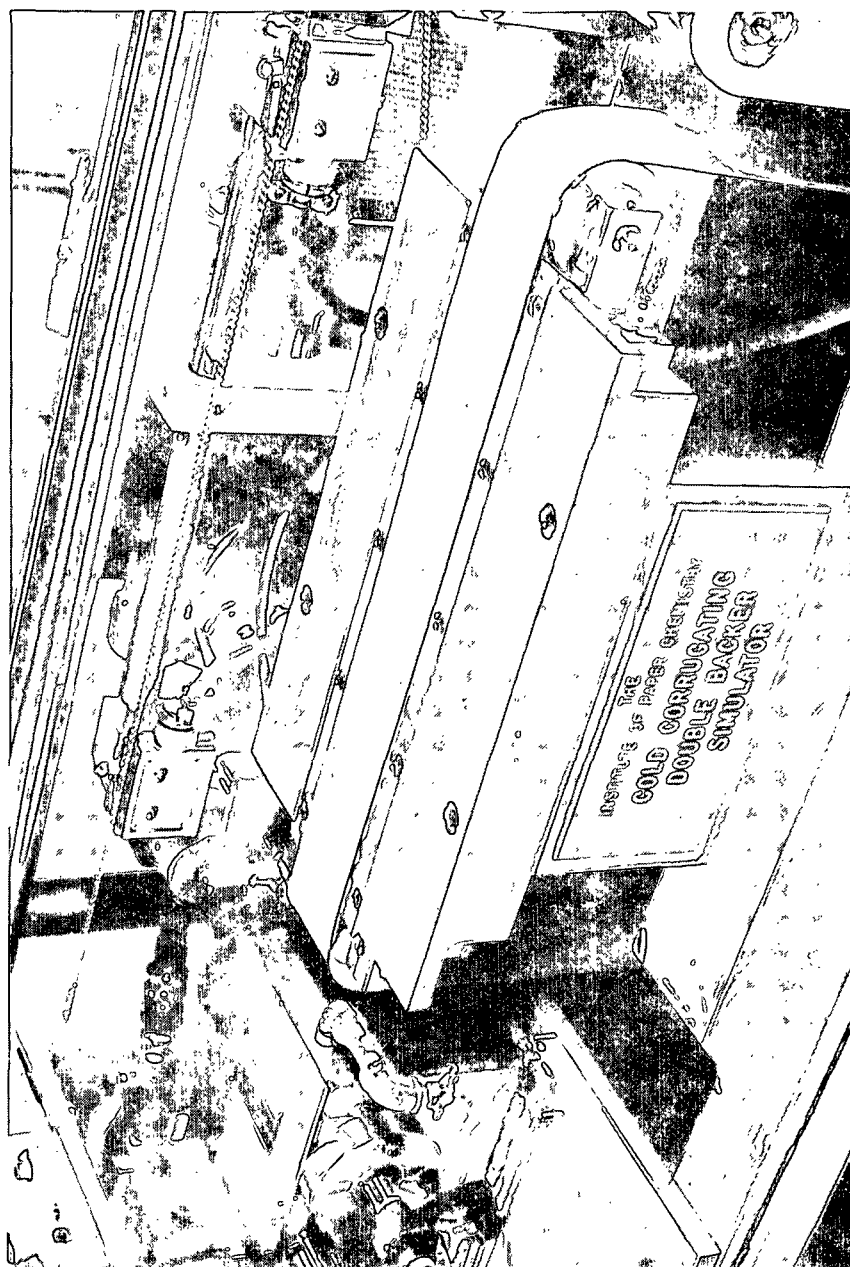


Figure 5. Adhesive Application Section and Air Table Combining
Section of Double Backer Simulator

the idle motor and engages it to be driven synchronously at the carriage speed. The double face liner also moves synchronously with the sample carriage.

As the first flute of the single face sample contacts the double face liner, two control timers are activated and air pressure is supplied to the air loaded combining section. The first 3 inches of the combining section are under the control of one pressure regulator, while the last 12 inches are controlled by a separate regulator. This provides for an initial high pressure segment for better bonding, if desired, while allowing the remainder of the combining section to operate at normal double backing pressures. A Teflon coated belt is used between the air supply ports and the bottom of the double face liner to more evenly distribute the air pressure and reduce drag. The sample carriage continues until the first flute reaches the end of the air table, at which time the carriage stops.

One of the two control timers determines the length of time that the air pressure is applied to the combined board to simulate the actual time under the top belt of the double backer. The second timer controls the time from bond formation until the start of bond breakage. When this timer deactivates, the sample carriage moves forward at a predetermined speed (typically, one flute per second) to initiate bond breakage. As the carriage moves forward, the double face liner is moved along at the same speed by the liner pull rolls. However, the liner is pulled down over the end roll of the combining section and away from the single face sample (see Fig. 5, extreme right). This places the bond of each flute under tension as it passes over the end roll and causes it to fail. The tension in the liner increases momentarily as the carriage moves and then drops off as each bond fails. The load cell system measures this liner tension. The recorder plots a graph of liner tension and, hence, bond strength as a function of time. The test cycle continues until all of the bonds have been broken and then automatically stops.

A typical graph for a test cycle appears as Fig. 6. Bond strength appears on the vertical scale and bond age appears on the horizontal scale, increasing from left to right. At the top of the graph is an event line which drops slightly as the first flute contacts the double face liner. At this point, the air combining pressure is applied. Counting to the right from this point to any bond break at one second per major graph division determines the age of that particular bond. The event line returns to its normal position when the air pressure control timer deactivates. For each test, this identifies the amount of time that the combined board was under pressure. In the example of Fig. 6, the board was under pressure for 5-1/2 seconds.

Looking at the main curve in Fig. 6, it can be seen that prior to the start of the trial the recorder pen is at midscale on the graph. As the test cycle begins the recorder first shows the liner tension induced by the weight attached to the liner, about 2.2 pounds. As the cycle continues and the single face flute tips contact the glue roll and then the double face liner, the load cell output becomes irregular due to vibrations in the drive system. Notice that the liner tension decreases as bonds are formed and the sample carriage provides some of the driving force for the liner. When all of the flutes have contacted the liner, the liner tension reaches its lowest point and the irregularities disappear.

In the bond breaking portion of the test cycle, the first few bonds exhibit low strength. As the cycle continues, however, the bond age and hence the bond strength increases as the adhesive continues the curing process. The presence of flute-to-flute irregularities, due in part to the high-lows, is evident. For this reason, ten trial runs are averaged to give statistically reliable results.

Adhesives can be effectively compared with respect to rate of bond strength development and final bond strengths by plotting bond strength as determined from

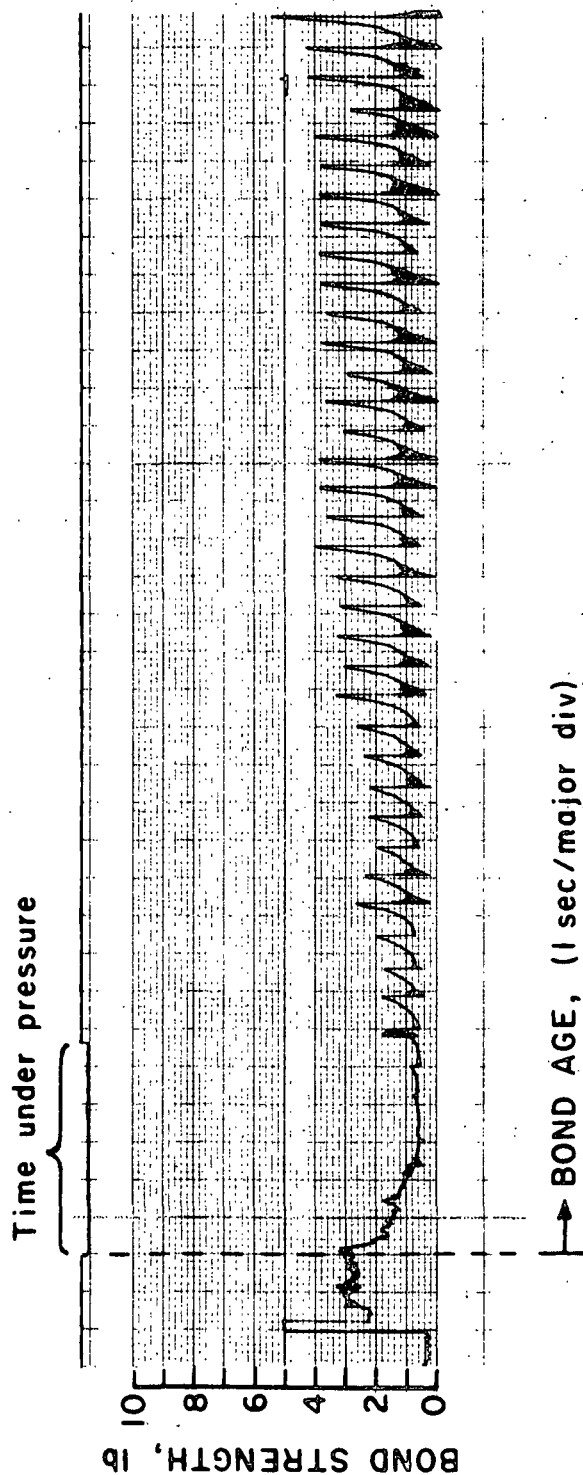


Figure 6. Typical Bond Strength-Bond Age Recording from Double Backer Simulator

the peaks of the graph as a function of bond age. Control adjustments on the simulator permit these comparisons to be made for any simulated speed of production, double backer length, combining pressure, glue application rate, component combination, etc. Thus, the double backer simulator provides an extremely efficient and versatile tool for the evaluation of adhesives.

Experimental Results

Most of the setback adhesive formulas evaluated over the past few years have much in common in terms of makeup, preparation and properties. All start as pearl cornstarch slurries with ammonium persulfate as a modifier, all are jet cooked, and all are postadjusted in pH by the addition of 50% NaOH. Variations take the form of recipe proportions, other slurry additives, variations in cooking conditions, variations in final pH and other postcooking additives. For comparative purposes, a simple formula used frequently in pilot trials has been selected as a base line adhesive. Performance of this adhesive on both the pilot equipment and the simulator is known so that it can be used as a realistic reference for evaluating other adhesives from simulator data.

Since the purpose of this report is to present a rather broad overview of the status of development of the cold corrugating process rather than a detailed review of any of its aspects, only a few key data will be presented. Subsequent reports will present more detailed information on all development results. In particular, results from the base line adhesive plus a few of the most promising adhesive formula variants will be presented.

The base line adhesive is formulated and prepared in accordance with the following recipe:

Slurry

Starch solids = 36% by weight
Ammonium persulfate = 0.3% on oven-dry solids by weight

Cooking conditions

285°F at 50 psig for 150 seconds

Final pH and holding conditions

pH = 9.0
Holding temperature = 190°F

Adhesive properties

Starch solids = 32% by weight
Adhesive viscosity = 220 Brabender units = 385 cps

This adhesive has given excellent results on both IPC and the PCA cold single facers with final bond strengths in excess of 5 lb/lineal inch, starch consumption rates as low as 1.0 lb/M ft², and speeds of 600 fpm. Bond failures usually occur within a component rather than within the adhesive or at an interface.

When used as a trial adhesive for the production of combined board the base line adhesive is completely adequate for the single-facing operation as previously noted. Double backer production speed is limited, however, to about 300 fpm by the onset of slitter edge delamination. At speeds above 300 fpm, the degree of loose edge is too great to be commercially acceptable. Hence the base line adhesive is not satisfactory for high-speed production of combined board and other formulas with faster bonding have been sought. Construction of the double backer simulator was prompted primarily by this goal.

Slitter edge delamination results directly from the lack of sufficient bond strengths to withstand the slitting operation. Since, at 300 fpm, the slitter is encountered about 16 seconds after the start of the bonding process, it appears that the bond strengths of the base line adhesive, after 16 seconds of curing, is

just sufficient to withstand slitting. This bond strength value thus serves as a useful reference in projecting maximum operating speeds for other formulas. A plot of normalized bond strength versus bond age is shown in Fig. 7. The normalizing factor is the bond strength of this adhesive at age 16 seconds.

This curve exhibits a plateau in the critical time period from about 10-15 seconds where the bond strength remains nearly constant, independent of time. This is characteristic of most simple AP modified starch adhesives and is a serious deterrent to the achievement of satisfactory performance. Figure 8 shows data for a similar formulation with less AP modification although the plateau is less pronounced, it is still present. The lower AP adhesive does give faster bond development as clearly indicated by relative bond strengths.

Numerous other adhesive formulas have been evaluated and show varying degrees of performance. Of these, the best available formulation to date is one with 1% or less acrylic acid in the slurry. Figure 9 shows comparative bond strength versus bond age data for the base line adhesive and for the acrylic acid adhesive. Clearly, the acrylic acid adhesive shows faster bond development, especially in the critical time region around 8 seconds. Since the base line adhesive is known to have a double backer production speed limit of 300 fpm, higher production speeds are projected for the acrylic acid adhesive. A plant trial will be used to verify this projection.

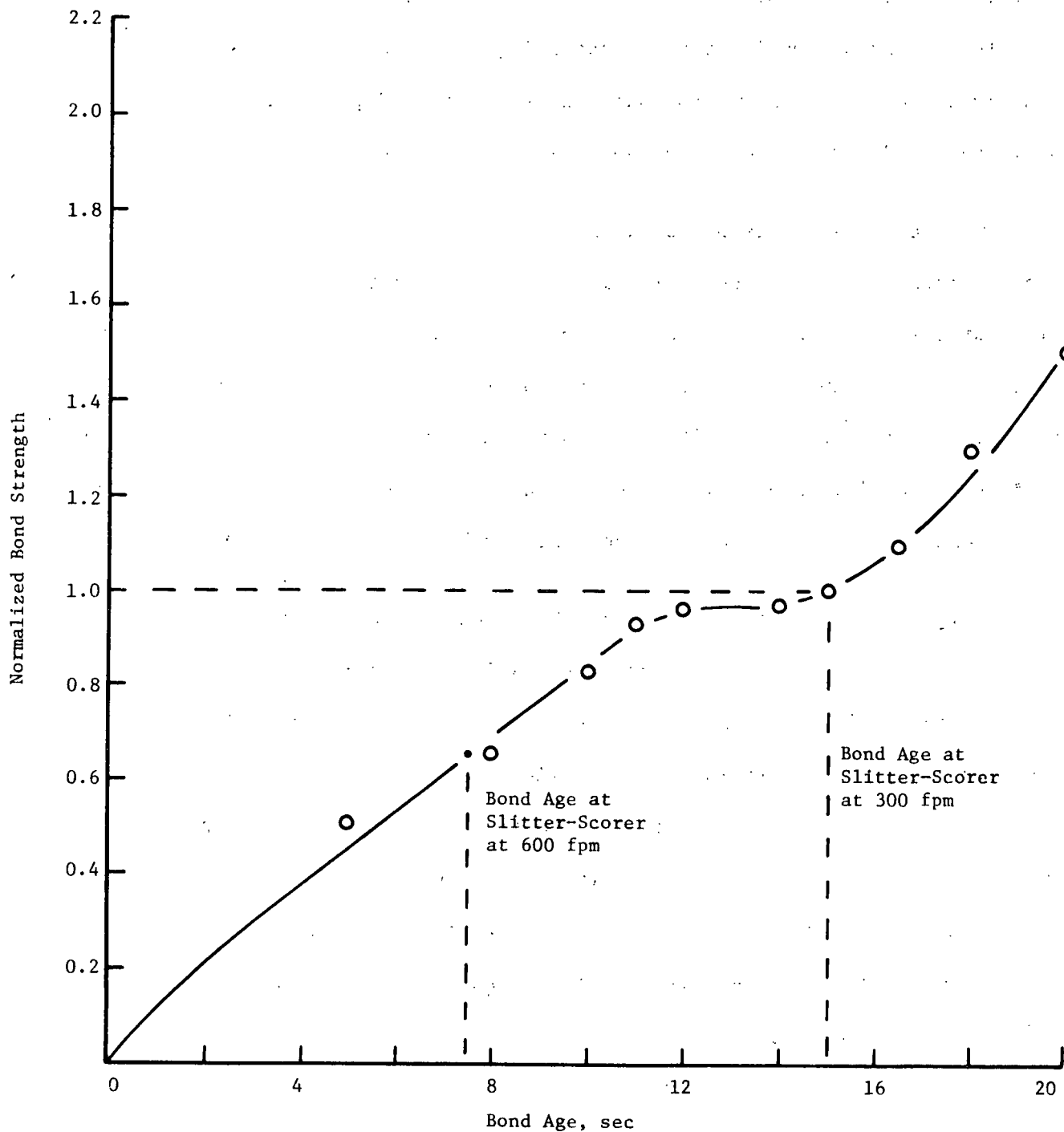


Figure 7. Normalized Bond Strength Versus Bond Age for the Base Line Adhesive

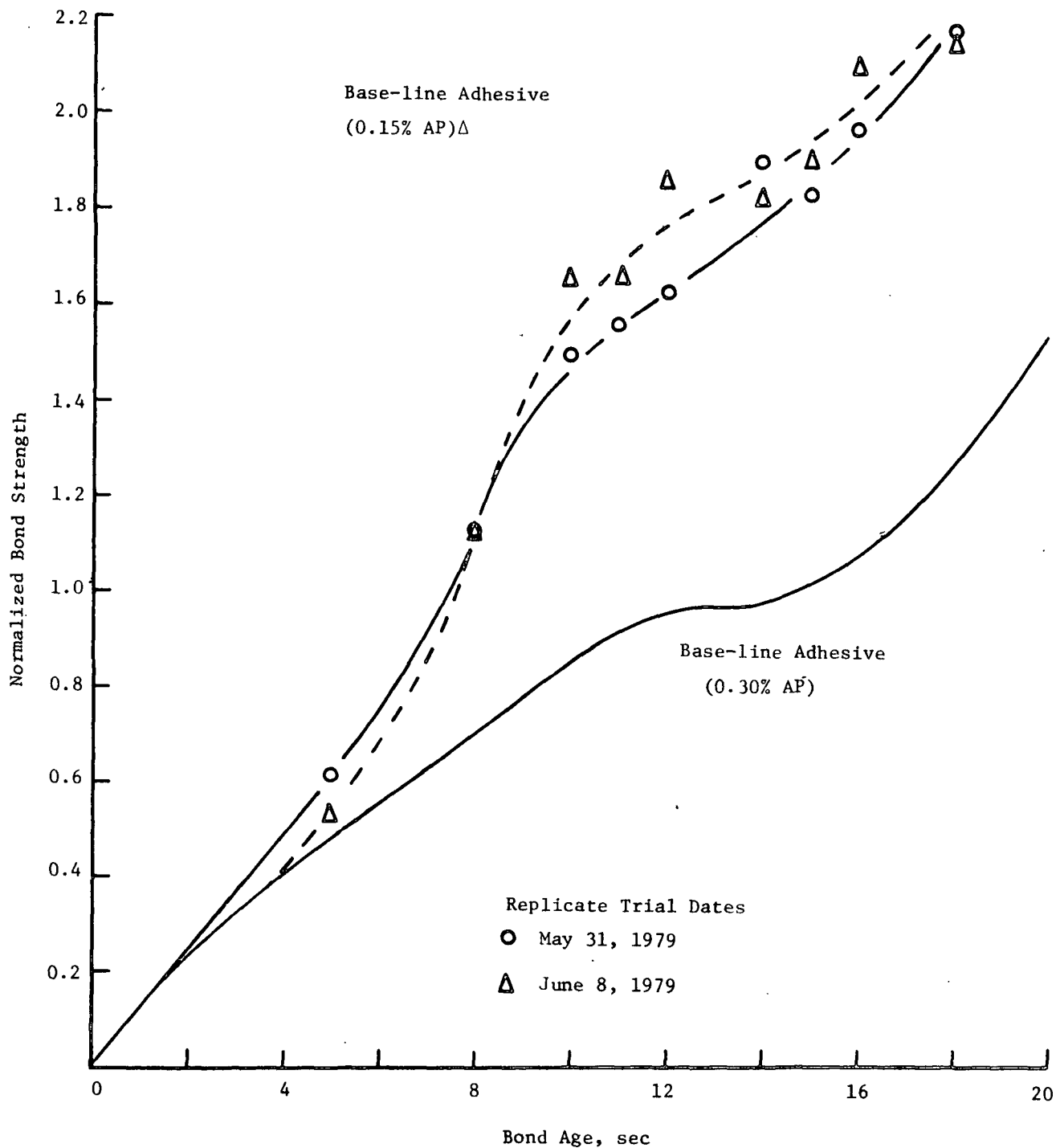


Figure 8. Relative Bond Strengths of Two Adhesives With Different Degrees of AP Modification

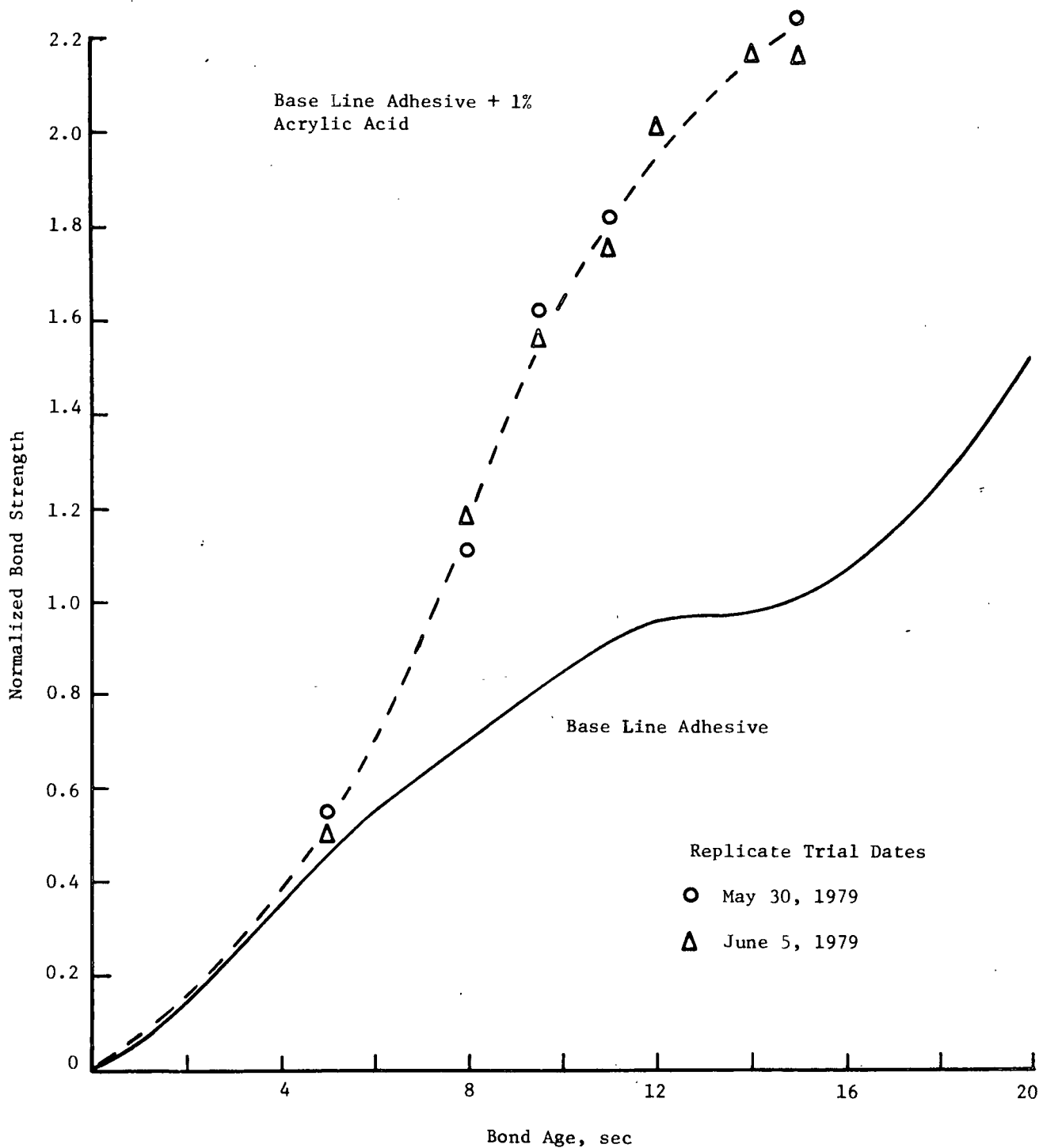


Figure 9. Comparison Trials of Base Line and Acrylic Acid Modified Adhesives

PART II.— FORMING PROCESS RESEARCH

INTRODUCTION

One of the two fundamental subprocesses in a successful cold corrugating process is that of forming the flutes in the corrugating-medium without the use of heat or shower steam, i.e., a cold forming process. In carrying out a fluting or forming process, any of several forming problems may be encountered. These include (1) flute fracture or limited runnability, (2) fiber picking on the corrugating rolls, (3) excessive flute height variations or high-lows, (4) gross anomalies in single-face flute form, and (5) deficiencies in flute structural properties. In hot corrugating, heating and showering of the medium presumably result in a softening of the medium, a reduction in friction coefficient, and finally, a reduction in the forces of attraction between the medium and the corrugating rolls. Under these conditions, the medium is formed and molded to give desired structural properties.

When the medium and the corrugating rolls are run cold and dry, as in cold forming, other mechanisms must be brought into play to achieve the same end. Specifically, cold forming processes must include factors that reduce forming loads to avoid fracture, factors that enhance release to minimize picking, and a machine designed and operated properly to avoid the other problems. Three approaches can be taken either one at a time or in combination; these are pretreatment of the medium, changes in the forming machinery, and changes in medium properties. Early work concentrated on the first; more recent work on the latter two.

MEDIUM TREATMENT AGENTS

Flute fracture or limited runnability is an impediment to achieving top productivity and board quality in the hot corrugating process and has been a

target for improvement for some time. One of the most effective approaches to this problem is the use of low molecular weight polyethylenes such as Epolene N-11 from Eastman Chemical Products, Inc. This material can be abraded onto both surfaces of a troublesome medium and usually contributes a significant improvement in runnability. Exploratory and early development work in cold forming followed similar avenues but with materials better suited to a cold sheet and a cold machine.

Progress Report One (March 12, 1976) presents the results of a broad study to find the best agents and application schemes for this approach. The methodology for identifying and evaluating candidate materials will be repeated below. Out of this early work, one of the best materials identified is a blend of 93% Mobilwax 130 (a low melting point wax), 5% stearin, 1% graphite, and 1% silicone oil. In this mixture, the wax and graphite are believed to be effective in preventing flute fracture, stearin is believed to act as a release agent to reduce fiber picking, and the silicone oil is added because it tends to improve high-lows.

Application of the above blend was accomplished by molding the mixture into solid bars and then abrading the material onto both sides of the sheet in a nip formed between two bars. An apparatus for accomplishing this task on a 98-inch pilot machine is described in Part IV. Application rates vary with hardness of the medium treatment agent (MTA), sheet roughness, nip angle, and web tension but typically amount to only a few pounds per million square feet. Costs typically averaged less than a penny per thousand square feet.

For convenience of notation, the above described MTA will be referred to as the standard blend. While the standard blend has certainly proved effective as an aid to cold forming, the material is difficult to mold because the graphite

comes out of suspension as the bar solidifies and it has not been proven or optimized with heavy weight medium and several other materials. Because of this, an additional search was undertaken to find better agents. Results of this work are described below.

NEW MEDIUM TREATMENT AGENTS — SELECTION AND EVALUATION

Screening Procedures

In a continuing effort to identify medium treatment agents with better performance and lower cost, several additional materials have been evaluated since the last progress report. Initial screening was carried out by measuring the coefficient of kinetic friction between a strip of medium treated with a particular agent and a conditioned metal foil. As a second screen, a runnability index was established on a runnability tester by testing a medium strip treated on both sides with the candidate agent. As a final performance evaluation, a 12-inch medium was corrugated after treatment on both sides. Maximum running speed without fracture or maximum web tension at fracture at maximum running speed were used as performance indices. Materials that perform well in all of these tests were used in the actual production of single-face board to permit evaluation of other performance characteristics of interest.

Candidate Materials

Seven agent blends were prepared by the Shell Oil Company to meet the requirements of medium treatment agents. Samples of these agents were delivered for testing but the formulations were retained by Shell until the evaluations were completed. Basically, these agents are blends of one or more waxes with varying degrees of hardness, and small amounts of diethylphalate as a release agent.

Three blends were prepared by Witco Chemical Company on the basis of thermal analysis of the standard agent blend supplied by the Institute.

Test Results

The seven agent blends received from Shell Oil Company were evaluated to determine coefficients of kinetic friction and runnability indices. Although there were minor differences in the friction data, all Shell materials performed quite well with friction coefficients from 0.11-0.14. Runnability indices were more variable with all Shell materials having roughly the same index as the standard treatment agent blend. (For reference, the standard blend consists of 93% Mobilwax 130, 5% stearin, 1% powdered graphite and 1% silicone oil.)

On the basis of material cost, agent performance and agent physical properties, three materials were selected for corrugation tests; (-1) Shellwax 100, which is inexpensive, shows excellent runnability and has acceptable physical properties for molding and handling; (-3) a blend of 98% Shellwax 100, and 2% diethylphthalate, which also shows good runnability; and (-5) a blend of 96% Shellwax 100, 2% Shellwax 700, and 2% diethylphthalate, which shows good runnability and excellent physical handling and molding properties. Mobilwax 130, the wax used in the standard blend, and the standard agent blend were also used as controls. Four mediums were used for the corrugation tests. Performance levels of the three Shell blends were equivalent, one to another, and comparable to both controls in all cases and superior in many. Picking, sometimes a problem with the standard blend and some mediums, seemed to be reduced and at times eliminated by the Shell materials.

Friction coefficients for the three Witco Chemical agent blends were only slightly higher than those for the Shell materials or the standard blend.

Runnability indices averaged about 30% lower however. Because of these low runnability values, corrugation tests were deemed unnecessary.

Of these new materials, Shell -5 has been selected as the most attractive material and continues to be used in some tests.

FLUTE PROFILE CHARACTERISTICS

In cold forming, one is basically trying to produce flutes that:

- a. Exhibit caliper within an acceptable range,
- b. Have high-low differentials sufficiently small to avoid deficiencies in double-face bonds,
- c. Do not release fiber or other materials to adhere to the corrugating rolls (picking),
- d. Do not fracture or sustain significant structural damage,
- e. Exhibit acceptable structural properties -- primarily flat crush.

The initial approach to cold forming has been to use medium treatment agents (MTA) abraded onto both sides of the medium in very small quantities. These agents typically contain ingredients aimed at items b, c, and d in the list above. Numerous agents have been blended and evaluated and many are useful in achieving the desired results. These were described in the previous section.

Despite the success of cold forming with medium treatment agents, it is desirable to develop methods for cold forming that do not require special treatment. Some exploratory work toward this goal has been undertaken so it may be useful in the context of this report, to summarize the state of development of cold forming, to describe work that is presently underway in this area, and to point to other possible areas of interest.

Caliper and Roll Design

Flute caliper for cold formed board is always significantly higher than for hot formed board, usually by several mils. Despite the difference in caliper, draw factors are about the same for both processes, thus clearly establishing that the cold process utilizes the medium more effectively. Some representative draw factor and caliper comparison data are given in Table I.

TABLE I

CALIPER AND DRAW FACTOR COMPARISONS FOR HOT AND COLD FORMING

	<u>Draw Factor</u>		<u>Caliper</u>		Equivalent Caliper Difference
	Hot	Cold	Hot	Cold	
A-flute	1.570	1.570	193	200	7.0
C-flute	1.443	1.422	157	160	7.6

Since the additional caliper resulting from cold forming is not required from a board performance point of view, commercial cold corrugators should be designed to yield board calipers comparable to those for the hot process. This may result in a reduction of the draw factor by a proportionate amount and hence a reduction in medium consumption. Some very definitive tests are planned to determine what, if any, savings are to be realized.

In the cold process, the medium is formed cold and without moisture addition. Thus, there is not postforming shrinkage due to cooling and drying. Also, flute tip compression on a cold formed flute is about 1/3 that for a hot formed flute. These two factors are believed to be the principal contributors to the increased caliper and medium utilization efficiency.

High-Lows

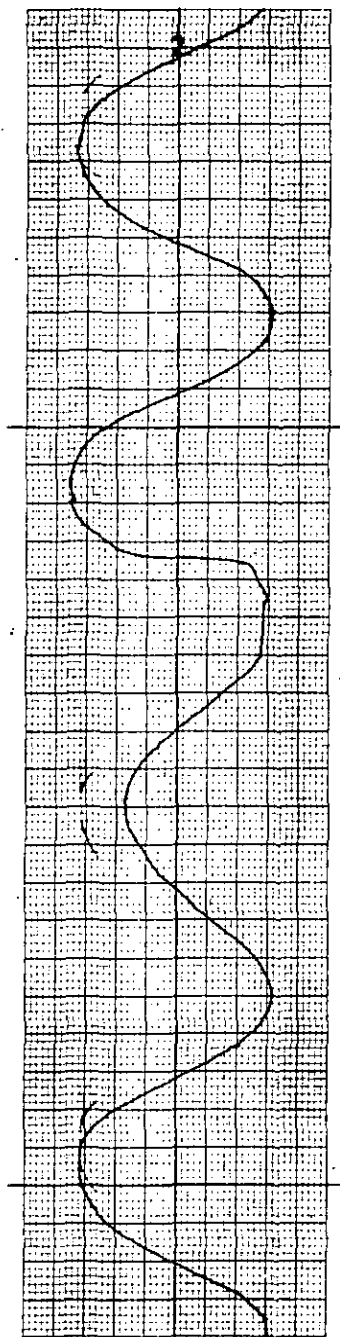
Considerable effort has been devoted to the development of medium treatment agents and corrugator operating conditions to minimize high-lows. Satisfactory performance (high-low differentials that average less than 2.0 mils) has been achieved with several MTA formulas but higher than normal top roll pressure has also been shown to be helpful in keeping high-lows to a minimum. Finger adjustment is also critical.

High-low formation is not a problem of particular significance to the cold process but more information about the impact of medium properties and forming variables is needed. This information will be derived from the process mapping studies described in the cold corrugation research plan. A new laser flute profilometer will be of great value in reducing the labor intensity and tedium of profile measurements while simultaneously yielding substantially more information.

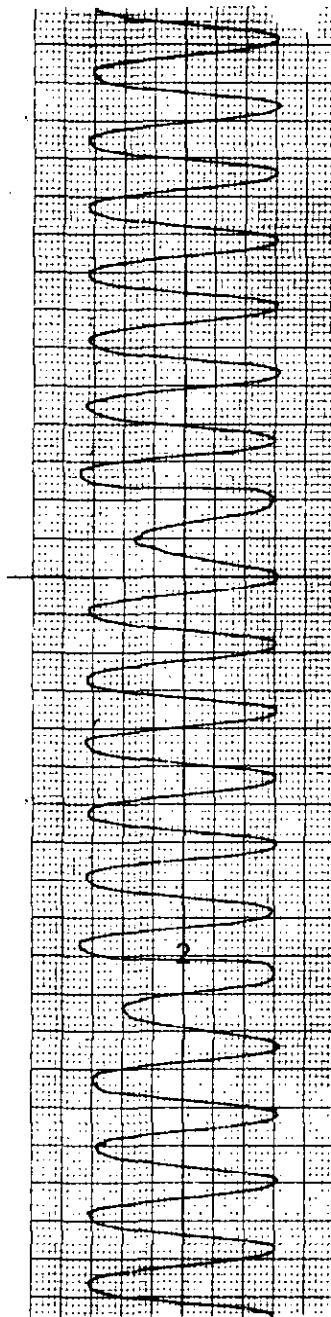
Flute form anomalies of another kind have been encountered in single-face trials on the 98-inch commercial machine. These take the form of short segments of individual flutes that are seriously distorted and dispersed randomly in the machine and cross-machine directions. A typical segment is 8-10 inches long. Two short profile recordings, shown in Fig. 10, illustrate the nature of the form.

Initially these were thought to be caused by roll bounce within the wide clearance of the bearings sized for hot running. Replacing these with bearings sized for cold running did not help.

Subsequently it was observed that the release of the single-face web from the pressure roll nip fluctuates with time in a repeating pattern, presumably



EXPANDED SCALE RECORDING OF ONE DISTORTION AREA



RECORDING SHOWIN TWO DISTORTION AREAS

Figure 10. Profile Recordings from Single-face Board with Flute Anomalies

due to poor release from the lower corrugating roll. To prevent this, a deflector roll was installed as close as possible to the point of release from the nip to force the single-face web to release cleanly. There is some evidence that the roll improves performance, although careful machine tuning and/or a fingerless design may be satisfactory alternatives. Summary profile geometry statistics are shown in Table II. These data favor use of the deflector although the differences are not dramatic.

TABLE II
PROFILE GEOMETRY STATISTICS FOR BOARD MADE
WITH AND WITHOUT DEFLECTOR ROLL

Speed	Deflector Used	Caliper	Average	High-lows	Valley Period Difference	+ Slope	- Slope
				% 4 Mils or More			
400	Yes	161.2	2.01	15.4	3.67	1.911	1.771
400	No	160.9	2.44	22.8	2.97	1.871	1.732

Fingerless corrugator designs expected for commercial application of the cold process may be very beneficial in minimizing high-lows.

Fiber Picking

Medium treatment agents with good flute release properties have been developed but picking is still encountered on occasion. It is believed that the frequency of picking is related to at least the following factors.

- a. Release properties of the treatment agent
- b. Surface finish and material of the corrugating roll
- c. Medium surface properties including cleanliness and the presence of loose shives or nonfibrous particles

- d. Dryness of the corrugating rolls — because the rolls are cold, any stray water vapor condenses on the rolls and contributes to picking
- e. Corrugating roll flute profiles may also be a factor in the picking process

In the event that forming is accomplished without treatment agents, fiber picking may occur more frequently. It is thus important to direct proper attention to this aspect of the forming process.

Several steps taken in the conversion of the commercial corrugator have proved effective in reducing the frequency of picking. These include protecting the corrugating rolls from water vapor through use of vapor barriers and air purge and cleaning the web of loose fiber and particles with an air jet. These features should be built into commercial machines as well. Beyond this, the rolls should be designed with optimum profiles and surface properties for minimizing fiber adherence to them.

Flute Fracture

Flute fracture is the most dramatic type of forming deficiency and one which cannot be tolerated in any form. The tendency to fracture is a strong function of medium properties and weight, of medium pretreatment, and of the forming process parameters. Early work in developing MTA's and the ability of these materials to reduce fracture tendencies has been amply documented in previous reports. Not enough work has been done, however, to characterize the performance of these materials over the full spectrum of medium types and weights. This will be undertaken as a part of the process mapping study mentioned earlier. Finally, it is desirable to explore ways of cold forming that do not rely on MTA's.

Flute fracture is believed to be primarily a tension failure resulting from excessive tension buildup in the forming operation. Medium treatment agents reduce the drag and shear forces on the medium and hence the tension loads. Other mechanisms for reducing tension are also available. These include reducing the wrap on the top corrugating roll via an idler roll at the nip, feeding the web directly to nip under low but controlled tension, and powering the top roll to reduce the tension inducing transverse loads on the medium caused by transmitting the torque required to drive the top roll through the flute flanks.

All of the approaches listed above have received limited evaluation but before presenting those results, it is necessary to describe the top roll drive. A sketch of the drive system is shown in Fig. 11. The corrugator drive motor is connected to a drive shaft through a multiple V-belt drive. This shaft drives the lower corrugating roll through a single stage gear reduction. Connected to this same shaft is a gear box with the proper ratios and drive sense to drive the top roll at the same speed as the bottom roll. The output shaft of the gear box is connected to the top roll through two gear couplings and a shaft. This permits the necessary transverse motion of the top roll. Inside the gear box is a mechanical phase adjuster which can be set so the bottom roll provides all the torque for the top roll or vice versa or anywhere in between. The adjustment is external to the gear box and can be changed while the corrugator is running.

The first step in evaluating these various mechanisms was to prepare single-face board samples and look for changes in draw factor, caliper, flat crush, high-lows, etc., as a function of the forming process configuration and adjustment. Data from these tests are presented in Table III. These data were all obtained while using MTA's to avoid any problems with flute fracture.

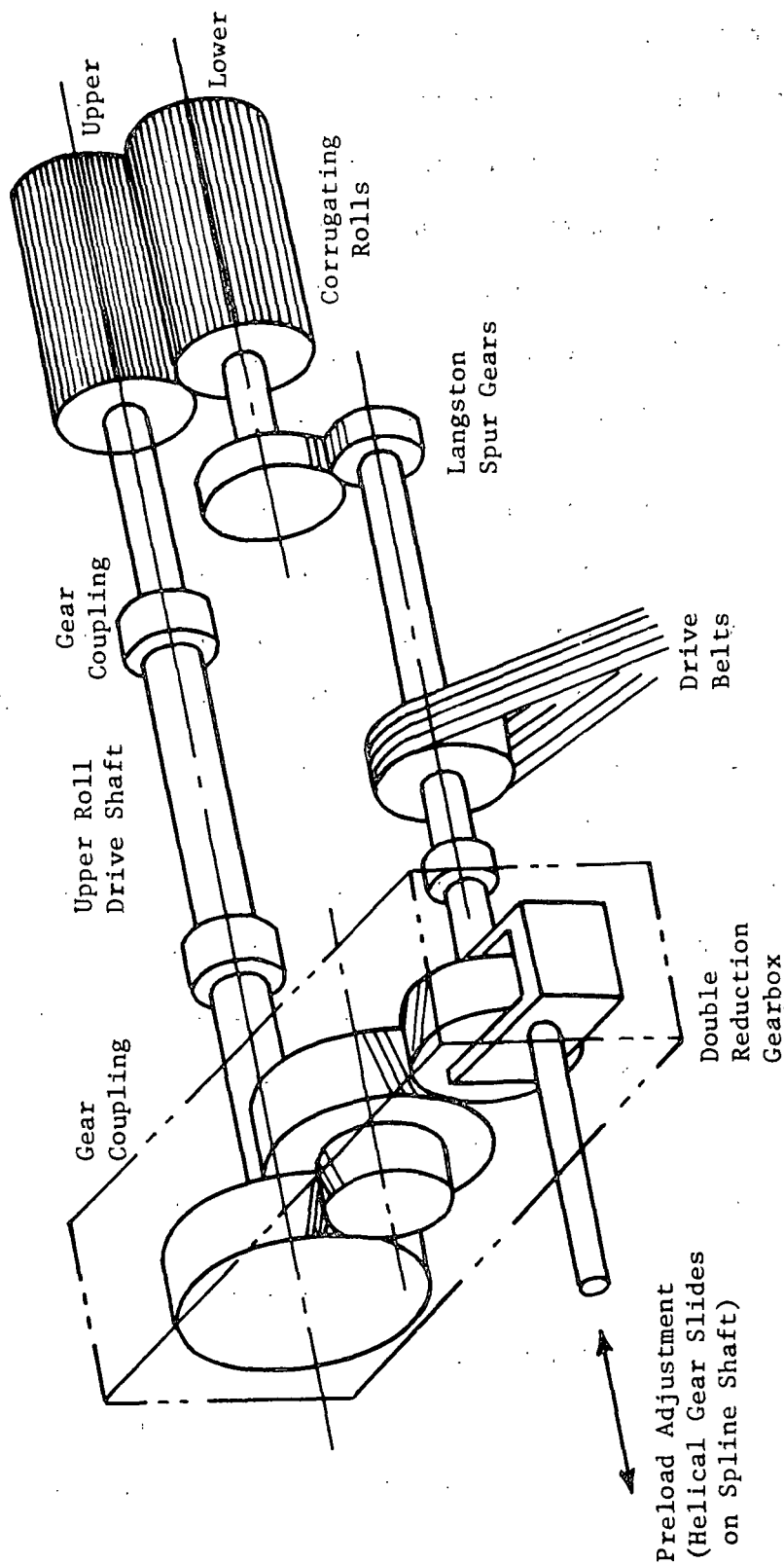


Figure 11. Top Corrugating Roll Drive Mechanism

TABLE III
IMPACT OF FORMING VARIABLES ON DRAW FACTOR, CALIPER AND FLAT CRUSH

Forming Process ^a			Corrugator Speed					
			200		400		600	
Dual Drive	Idler Roll	Web Feeder	Draw Factor	Caliper	Flat Crush	Draw Factor	Caliper	Flat Crush
--	--	--	1.439	156	26.6	1.437	157	26.2
--	X	--	1.437	157	26.7	1.440	157	30.0
0	--	--	1.431	155	28.4	1.431	156	26.6
0	X	--	1.436	157	29.5	1.433	157	29.9
0	--	X	1.447	157	28.2	1.451	157	28.3
1/8	--	--				1.430	156	25.8
3/8						1.427	156	29.0
5/8						1.433	157	28.1
3/4						1.434	157	25.0

^a0 = minimum top roll drive.
X = maximum top roll drive.

While there are minor variations in the numbers in this table, it is very difficult to discern any significant trends. Thus one is lead to conclude that under the range of forming process parameters tested, none has a significant influence on draw factor, caliper or flat crush.

The primary objective in changing the forming process is to improve runnability. Runnability is determined by mapping the operating speed-web tension values at the onset of fracture. The curve described by these data divides the operating plane into a safe region and a fracture region. The larger the safe region, the better the forming process, at least from a runnability point of view. Test data for this mapping operation are only partially complete and will not be included here.

Flat Crush

Single-face or combined board produced by the cold process consistently shows lower flat crush than for that produced by the hot process. Since flat crush is regarded as an important parameter, it is necessary to determine, and hopefully correct, the factors leading to the flat crush deficiency. Typical comparison data, illustrated in Table IV, show that for the cold process, SF flat crush is about 14% low and combined board flat crush 23% low. The SF value is the more valid measure since the cold combined board production system is too crude to achieve the full flat crush potential of the single-face board. This will be corrected in commercial designs.

Several factors are believed to contribute to the loss of flat crush. First, the flute caliper is higher. Assuming that flat crush failure is a typical column failure, critical load varies as the reciprocal of the square of column length. For a 5% increase in length (caliper), the corresponding decrease in flat crush is 10%.

TABLE IV
REPRESENTATIVE FLAT CRUSH DATA

Production Process	Medium Concora	Flat Crush	
		SF	DF
Hot	38.2	32.8	35.3
Cold	38.2	28.3	27.2

Second, there is some geometric asymmetry in all flutes as measured by flank slopes. This asymmetry seems to be larger, however, for cold flutes. Average positive and negative slopes for 103 flutes are shown in Table V for hot and cold process board made from the same components. The differences are clear.

TABLE V
FLANK SLOPE COMPARISONS FOR HOT AND COLD FORMING

	Average Flute Slope (103 flutes)		
	Positive Slope	Negative Slope	Slope Difference
Hot process	1.821	-1.863	-0.042
Cold process	1.763	-1.740	+0.023

This asymmetry is apparent in visual observation of the failures and is perhaps reflected in the load-deflection curves for flat-crush failure. Representative load-deflection curves for hot and cold-formed board are shown in Fig. 12.

Finally, there may be structural asymmetry in the flutes. Flank compression, for example, is usually greater on the driven side of the flute. Other differences may be present as well. As of now, no test procedures are known that will separate structural asymmetry from geometric asymmetry.

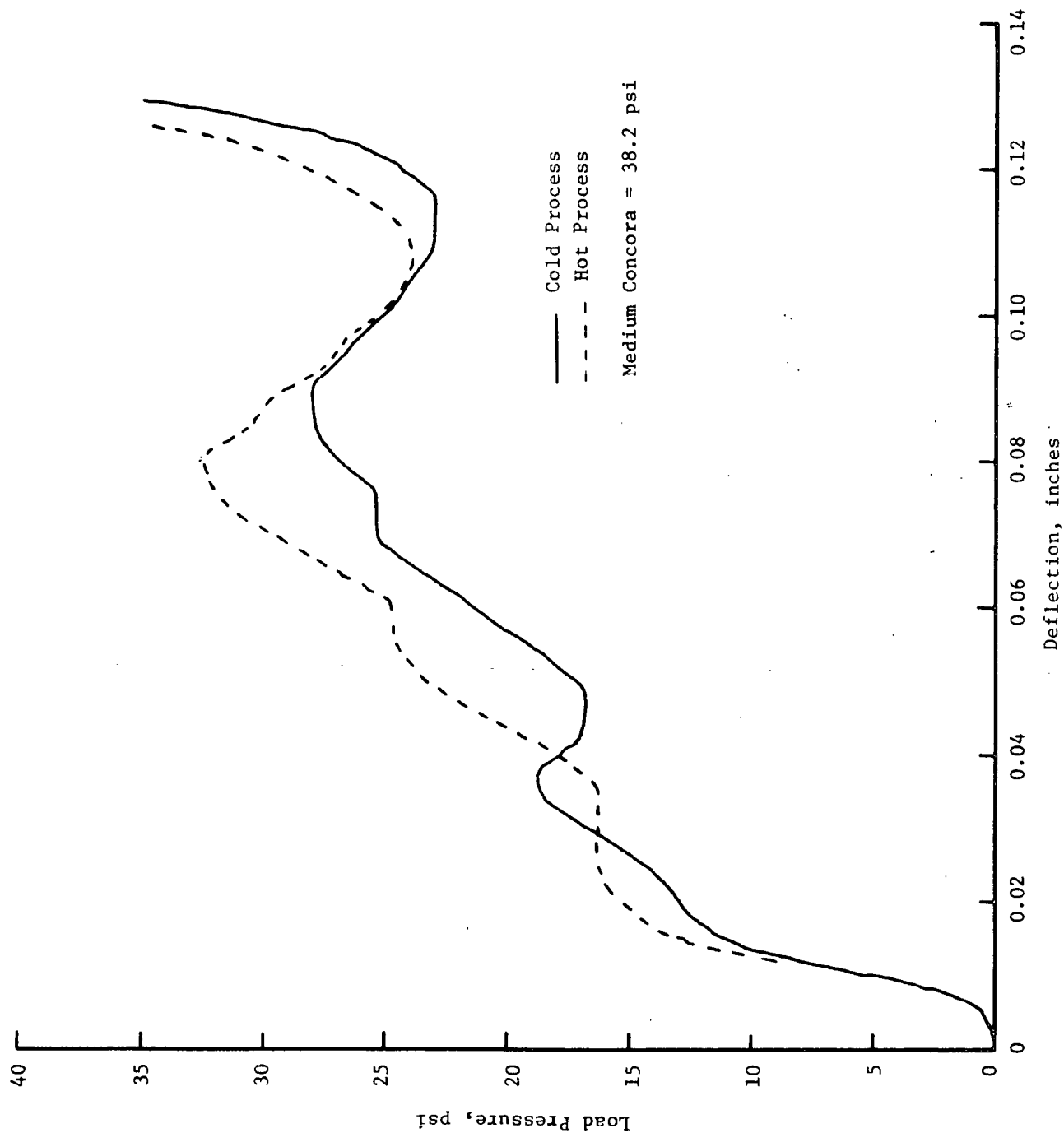


Figure 12. Load-deflection Curves for Flat Crush Tests of Hot and Cold Process Board

It is believed that corrective action can be taken once the factors contributing to the lower crush resistance are known. Work is continuing toward developing an understanding of these factors.

RUNNABILITY AND MEDIUM PROPERTIES

Very recently, several different 26 lb/M ft² corrugating mediums have been evaluated in single-facing trials with the objective of determining the impact of component properties on the single-facing operation. These data will be published in detail in a subsequent report after they have been thoroughly analyzed. One clearly evident result from the trials can be presented now, however.

Of the mediums evaluated in these trials, about 60% show excellent runnability in the cold process without the use of pretreatment agents. Thus, for this sample, more than half of the mediums have inherent properties that permit cold forming without any form of pretreatment. It appears that the excellent runnability is closely correlated to readily measurable medium properties but the details of this correlation will be presented later. Since so many mediums already have properties that are near optimal for cold corrugating, it would appear that the manufacturing processes for the others could be altered to produce the desired properties. For such mediums, cold forming could be accomplished on a conventional hot corrugator by turning off the steam supply and adding an idler roll to feed the web directly with the forming nip.

PART III — ECONOMIC ANALYSIS OF THE COLD CORRUGATING PROCESS

INTRODUCTION

Cold corrugation offers significant economic advantages over the hot corrugating process including reductions in process heat costs, savings in electrical drive energy, lower capital equipment requirements, reductions in waste and so on. At this stage of process development, some of these factors can be quantified. For others, estimates cannot be made until realistic commercial operating data are available. The purpose of this section is to present the economic advantages of the cold process as they are presently evaluated.

PROCESS HEAT COST SAVINGS

In cold corrugating, the corrugating medium is formed without the use of either heat or steam. Bonding of the medium and liners is accomplished with a starch-based adhesive that sets upon cooling and drying, that is, without the addition of heat. Heat energy is used in the process only to prepare the setback adhesive and to keep it warm until it is applied to the flute tips.

Preparing the adhesive requires only about 600 Btu per pound of dry starch. About 18.5×10^3 tons of board are produced on the average corrugator each year. Assuming an average board basis weight of 120 lb/M ft^2 , this corresponds to $3.08 \times 10^5 \text{ M ft}^2/\text{year}$. At 2 lb/M ft^2 of average starch usage, total starch consumption is about $0.6 \times 10^6 \text{ lb/year}$. The fuel-based energy required to convert this starch is about 360 million Btu if the boiler efficiency is 80%. At \$3.00/MM Btu, this energy would cost about \$1,000. For the industry the starch conversion energy would be about 0.3×10^{12} Btu at a cost of about \$1 million.

For 24 hot corrugators, process energy measurements made over the summer months, where there is no building heat load and minimal stray losses, show an average process heat consumption rate of 1.14×10^6 Btu/ton. Using this consumption rate and the average yearly production rate for a corrugator of 18.5×10^3 tons yields an energy consumption rate of 21×10^9 Btu/year/corrugator. This energy would cost about \$65,000 at \$3/MM Btu.

In addition to starch conversion energy, there is a small amount required to keep the adhesive warm. Accurate estimation of this quantity requires detailed design information for the adhesive handling system. Fortunately the number is too small to have significant impact. For purposes of this analysis it has been estimated at less than 1% of the process heat consumption of a normal hot corrugator.

These data can be summarized as follows:

Hot Corrugating	Per Corrugator Consumption Cost	Industry Consumption Cost
Process heat	21×10^9 Btu/year, \$65,000/year	16×10^{12} Btu/year, \$48 million/year
Cold Corrugating		
Starch conversion	0.36×10^9 Btu/year	0.27×10^{12} Btu/year
Adhesive heating	0.21×10^9 Btu/year, \$1710/year	0.16×10^{12} Btu/year, \$1.3 million/year

Thus the total process heat consumption for cold corrugating is less than 3% of that for hot corrugating.

ELECTRICAL DRIVE ENERGY SAVINGS

Electrical drive energy requirements for a cold corrugator will be less than those for a hot corrugator because of the elimination of several pieces of

driven equipment and several drag surfaces including the double backer. A preliminary estimate of these savings has been made for a representative two flute corrugator.

For this analysis, one corrugator is assumed to be in operation at all times during an average 48-hour week (single wall production), the second corrugator is assumed to run 25% of the time (double wall production). Horsepower and operating time breakdowns are shown in the following table.

Drive Location	<u>Drive Horsepower</u>		<u>Annual Operating Time</u>	
	Hot	Cold	%	Hours
Single facer 1	60	60	25	625
Single facer 2	60	60	100	2500
Double backer	160	80	100	2500
Miscellaneous drives	70	40	100	2500

These data are converted to fuel equivalent Btu values by using 746 watts/hp, 10,600 Btu/kw-hr, and 80% machine efficiency. Fuel costs are calculated at \$3/MM Btu. The resulting consumptions and costs are as follows:

Per year per <u>corrugator</u>	Hot	Cold
Electrical energy consumption	8×10^9 Btu	5×10^9 Btu
Electrical energy cost	\$24,000	\$15,000
Per year for <u>industry</u>		
Electrical energy consumption	6×10^{12} Btu	3.8×10^{12} Btu
Electrical energy cost	\$18 million	\$11.2 million

This saving, which is incidental to the cold process, amounts to about \$9,000 per year for the average corrugator.

CAPITAL EQUIPMENT SAVINGS — NEW INSTALLATIONS

Cold corrugating does not require any of the usual process heating equipment. Equipment that may be omitted includes all preheaters, preconditioners, showers, hot plate sections and steam handling equipment. Even the boiler may be reduced to a small unit. The double backing unit, in addition to being built without hot plates, will be simpler and have a low horsepower drive unit. Collectively these items are expected to yield a capital cost reduction of \$500,000 or about 25% of the cost of a representative installation. Maintenance costs should be reduced correspondingly.

CORRUGATOR WASTE

Total box plant waste averages about 13% or about 1.8×10^6 tons per year. About 31×10^{12} Btu are required to manufacture this amount of paper. A part of this waste is contributed by the corrugator through excess edge trim, warped sheets, and other production deficiencies. Cold corrugating is expected to reduce corrugator contribution to this waste and hence to reduce production costs and papermaking energy consumption. Without good operating data it is impossible to make realistic estimates of the savings. For perspective, however, a reduction of waste by 1% would save \$40,000 per year per corrugator. Thus this is an important quantity to monitor in commercial trials.

OTHER PROCESS ADVANTAGES

Cold corrugators will be cooler, quieter and safer than hot corrugators. The machinery will be simpler and more maintenance-free. Elimination of heating and moisture addition should make process performance less sensitive to speed changes. Multiwall production speeds should be higher since bonding will not be

heat-transfer limited as with the conventional process. The process will be more amenable to process automation for quality control, primarily because there are fewer variables to control or manipulate. As the process develops and commercial trials begin, realistic assessment of these advantages can take place.

ECONOMIC SUMMARY

The cold corrugating process will reduce process heat consumption by 97%, electrical drive energy by up to 40%, and capital costs for new corrugators by 25%. Adhesive costs will be competitive. Waste reductions, fiber savings, maintenance cost reductions, reductions in boiler room personnel costs, and other productivity improvements are real but cannot be quantified until operating data become available.

PART IV — PILOT TRIALS

INTRODUCTION

All of the early work in developing the cold corrugation process was carried out on a 12-inch pilot single-facer in the Container Laboratory at The Institute of Paper Chemistry. Clearly this machine is significantly different from commercial machines with respect to such factors as scale, operating condition, and operational environment. Design differences such as roll crown must also be taken into consideration. Furthermore, the IPC does not have double-backing and sheeting equipment and thus could not evaluate or develop these aspects of the cold corrugating process even on a laboratory scale. For these and other reasons, pilot-scale trials of the cold corrugation process are being carried out on a commercial-scale machine converted in the minimum way required to accommodate the new process. The purpose of this section of the report is to describe that conversion and the rationale for it, and to give operational and performance data for the converted machinery and for the cold process.

CONVERSION OF THE COMMERCIAL CORRUGATOR

Cold corrugation utilizes a different forming process and a different adhesive from the conventional process. As a consequence, four elements in the corrugating system must be changed to accommodate the new process. These are the single facer, glue machine, double backer and adhesive makeup and handling systems. All other elements remain unaltered. Basically these changes are governed by the need to run the machinery cold, to pretreat the medium, to keep the adhesive warm until it is used and by the fundamentally different adhesive makeup system. These conversion requirements for the various subsystems are described below.

Single Facer

Changes in the single-facer to accommodate cold running include the following:

- i. A medium treatment agent applicator was installed ahead of the single-facer to allow pretreatment of the medium before forming. This system is suspended from the corrugator bridge and is based on the use of 16 solid bars of agent, each 12 inches in length, with 8 above the sheet and 8 below. As shown in Fig. 13, the two rows of bars form a nip through which the web passes to abrade the agent onto both sides of the sheet. Application rate is controlled by the nip angle and the physical properties of the agent and, to a lesser extent, by web tension. As shown, each bar is independently suspended to permit relative motion between adjacent bars. This feature was included to allow the bars to accommodate to wrinkles, differential tension and so on. This has proved to be unnecessary and a rigid, full width holding system would function as well.
- ii. All steam connections to the machine have been removed so that the medium cannot be steamed and neither the medium nor the liner can be heated in any way.
- iii. The conventional adhesive pan has been replaced with a pan that has water jackets on the bottom, front and back, and both ends. Hot water is circulated through these jackets to maintain an inner surface temperature of about 190°F.
- iv. The pan is completely covered including end skirts. A small door over the glue roll is designed to permit covering the roll except when the machine is actually producing board.

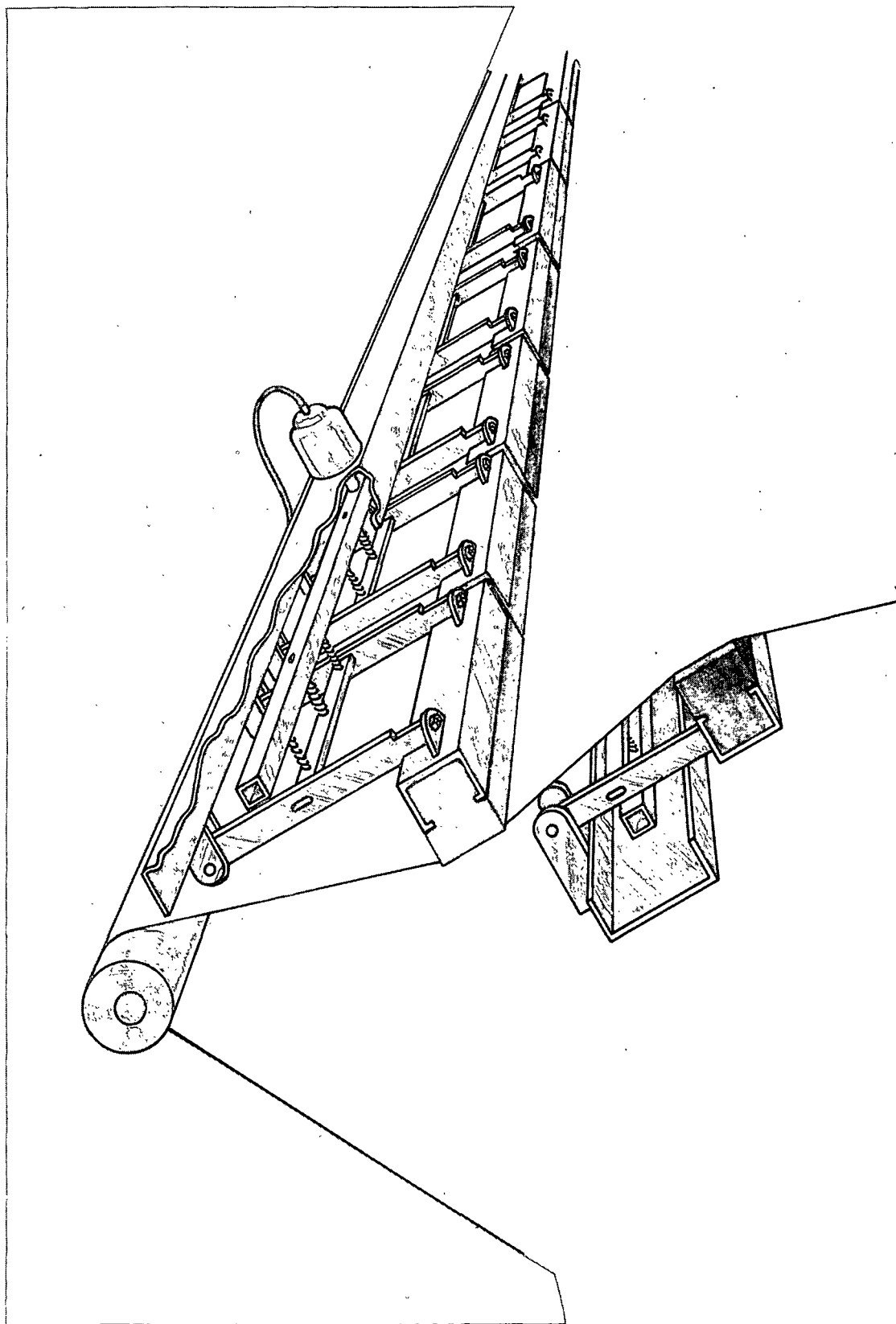


Figure 13. MTA Applicator System

- v. The metering and applicator rolls are bored and hot water is circulated to maintain the roll surface temperatures at about 190°F.
- vi. Despite the enclosure of the adhesive system, vapor from the aqueous adhesive escapes and rises toward the cold corrugating rolls. To prevent this vapor from condensing on the cold rolls and complicating thread-up, an air-jet purge system carries the vapor out over the pan. In addition, a rubber vapor barrier is installed over the finger holders and under the top corrugating roll.
- vii. In the adhesive pan, a side-by-side dual dam system is used to confine the overflow adhesive and minimize the wetted area of the system when narrow webs are run.
- viii. For durability in the presence of the hot operating environment, a phosphor bronze doctor blade is used on the metering roll.
- ix. In several early single-facer runs, distorted flutes appeared at random intervals, mostly toward the center of the sheet. These were more pronounced at higher operating speeds. Initially these were thought to be caused by bouncing of the rolls within the free-play of the high clearance bearings designed to absorb the expansion caused by heating. These bearings were replaced by low clearance bearings with no improvement in flute form.

Glue Machine

Conversion of the glue machine for cold running includes the following:

- i. A fully jacketed adhesive pan functionally like that used at the single facer is installed on the lower tier of the two-tier machine.

- ii. Simple front and back covers are installed during operation to minimize adhesive exposure. The remainder of the adhesive pool is covered by the rolls and blades in the normal machine. End skirts are not used.
- iii. Hot water is circulated through the metering and applicator rolls and through the pan jacket to maintain the temperature of all surfaces that contact the adhesive at about 190°F.
- iv. A flexible wiper blade is mounted above the normal metering nip at a trailing angle of about 25° to the tangent to the gravure applicator roll. A combination of mechanical adjustments and a full-length, pressurized rubber tube behind the flexible blade is used to insure full contact with the roll and to control the amount of adhesive remaining on the gravure roll. Hot water is circulated through the blade structure to keep the blade hot and avoid adhesive buildup.

Double Backer

For the cold process, both the double face liner and the steam chests are cold. To reduce the high friction between these cold surfaces, a high density polyethylene slip sheet, about 0.050-inch thick, is placed over the full length and width of the chests and anchored to the double backer frame. This material is sufficiently strong to withstand the rigors of installation and operation for several trials and has the lowest kinetic friction coefficient of any material evaluated for this purpose.

Note: Setback adhesives bond by combined heat and mass transport processes that begin immediately upon contact with the medium flute tips. Because of this, the open time resulting from the physical separation of the glue machine and the double backer could lead to a reduction in final bond strength, especially at low speeds for which the open time may be of the order of three seconds. To avoid this potential problem, a special combining section was designed to reduce the intermachine separation, and hence the open time, by 75%. Subsequent laboratory and pilot trials have revealed, however, that with present adhesive formulations there is negligible loss of bonding even at the lowest operating speeds. Thus the special combining section is not being used at the present time but will be retained in the event adhesive changes require its use. The details of design will not be given at this time.

Adhesive Handling System

Setback adhesives exhibit partially irreversible viscosity increases with cooling. Because of this, it is necessary to maintain the temperatures of the adhesive at about 190°F until it is actually applied to the flute tips. The hardware on the single facer and on the glue machine dedicated to this purpose has already been described. In this section, the adhesive delivery system will be described.

A very simple schematic of the adhesive handling system is shown in Fig. 14. In this system, Tank 1 serves as the catch tank for the adhesive make-up system and also as the supply vessel for the single facer. Tank 2 is the supply vessel for the glue machine. Pump 1 is used to deliver adhesive to the glue machine supply tank during the adhesive makeup cycle and then becomes the single facer supply pump during the run cycle. This two-tank system reduces recirculation distances and permits use of different adhesive formulations for the two stations although this has never been done.

For single facer operation, Pump 1 supplies adhesive to the single facer adhesive pan at the rate of 6-10 gpm. Excessive adhesive overflows the inner level control dams and is returned to the pan drain in the channel between the inner and outer dams. A small sump on the pan drain collects the overflow at the inlet to the return pump. A level sensor in the sump controls the return pump speed to keep the adhesive level in the sump constant. In this way, the return pump inlet is always flooded and air entrainment is minimized.

A similar adhesive circulation system is used at the glue machine.

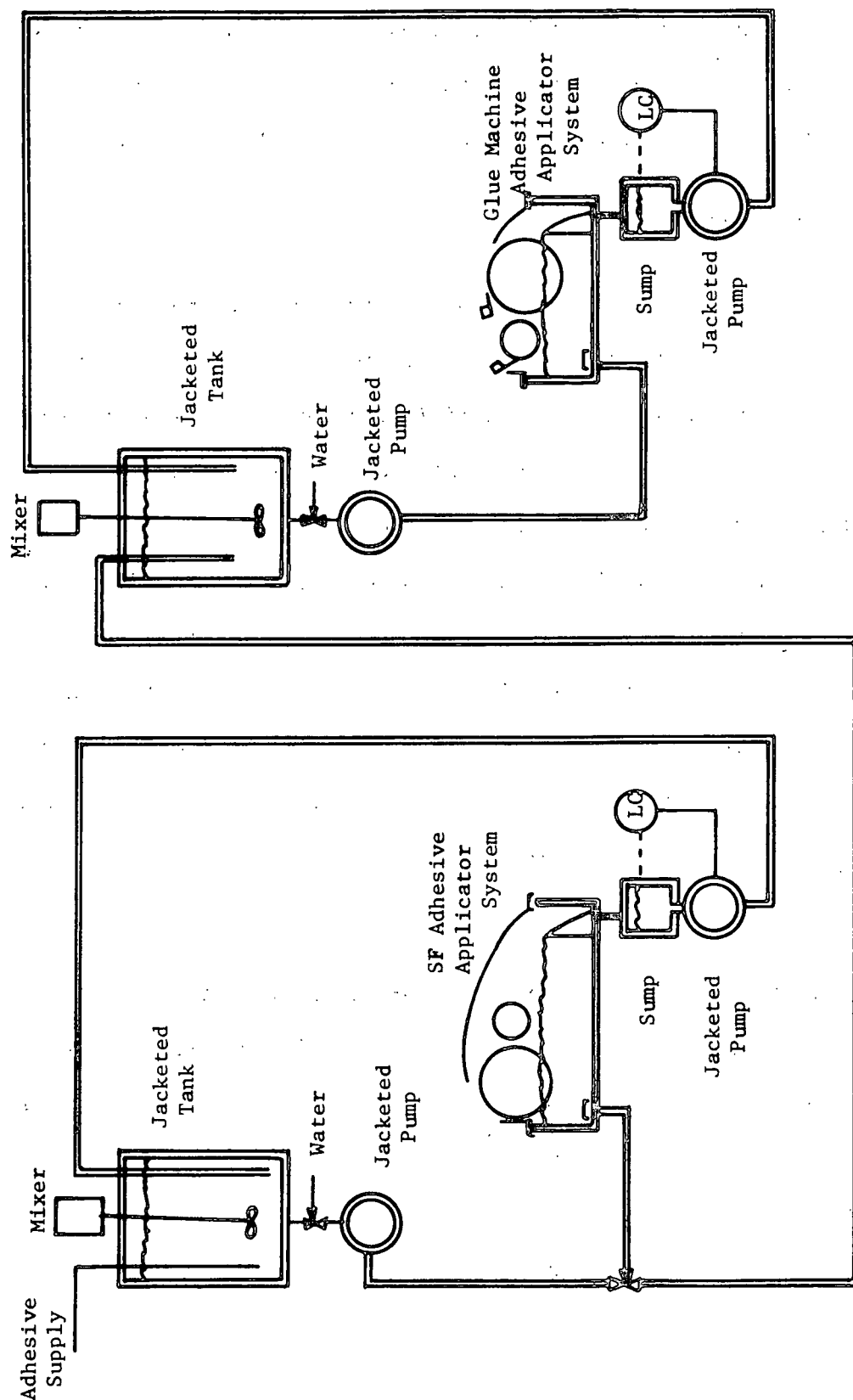


Figure 14. Pilot Plant Adhesive Handling System

In the adhesive recirculation systems, all tanks, pumps, lines and sumps are jacketed. Hot water is circulated through the jackets to maintain the temperature of the surfaces contacting the adhesive at about 190°F.

RESULTS FROM PILOT TRIALS

Over the past several months, the IPC project team has conducted several trials with the pilot system at the PCA, Burlington, plant. Many of these trials have been directed toward checkout and modification of conversion equipment to achieve satisfactory performance. Identification and removal of some of these early conversion deficiencies are discussed in earlier sections of this report and will not be treated here. Some trial runs were also conducted to evaluate process performance and process variations. Generally, however, once the equipment was put in proper order, successive trial runs produced comparable board properties. Hence, there is no need here to discuss each of these runs in detail; rather, the intent is to provide a brief summary of data representative of performance of the process at the present state of development.

Single-facer Trials

In the evolution of a suitably converted pilot system, attention was first given to the single facer. Hence, several trials were conducted with the single facer only. A representative comparison of board characteristics for single face board produced by the hot and the cold process on the same single facer is shown in Table VI. These data are representative of the performance achieved over the speed range from 100 to 600 fpm and are taken from an 85-inch web on the 96-inch machine.

TABLE VI

COMPARISON OF SINGLE-FACE BOARD PARAMETERS FOR THE
HOT AND THE COLD CORRUGATING PROCESS

Parameters	Typical Values Cold Board	Typical Values Hot Board	Units
Caliper	163 (4.14)	154 (3.91)	mils (mm)
Bond strength	14 (96)	11 (76)	psi (kPa)
Edgewise compression	31 (5.43)	30 (5.25)	lb/inch (kN/m)
Flat crush	25 (172)	27 (186)	psi (kPa)
Flute height differentials	1.6 (0.041)	1.8 (0.046)	mils (mm)

Notes: 1. Medium — 26 lb/M ft² (126 g/m²).
NSSC — Concora 53 lb (235 N).

2. Liner — 42 lb/M ft² (203 g/m²) kraft.

3. Hot and cold board made on same machine.

Briefly stated, the cold board compares favorably with hot board in every respect except flat crush which is usually lower. This stems, in part, from the higher caliper of the cold board. It is expected that cold commercial machines will be designed to reduce caliper to values typical of hot production. This, plus other anticipated process changes, should raise the flat crush values of the cold board. The data shown in this comparison are typical and can be achieved routinely on the converted machine.

Combined Board Trials

Several combined board trials have been conducted. To evaluate the cold process, consideration must be given to all the usual board properties and to production speeds with due consideration for the limitations imposed by the highly simplified pilot equipment.

As previously mentioned, successful operation of the single facer at 600 fpm has been routinely accomplished. The stop-start, short term nature of a combined board trial precludes operation of the single facer at a sustained high speed, however. This, plus the fact that the adequacy of single facer performance was well established before combined board trials started, resulted in a decision to operate the single facer continuously at a slow speed during a combined board trial. This is reflected in the data table presented below.

On the double backer, the maximum production speed is determined by the onset of slitter edge delamination. This, in turn, is directly related to the rate of bond development of the adhesive tested. Top production speed has varied from 300-500 fpm depending on the adhesive formulation. Slightly preheating the double face liner increases this top speed. Recently formulated adhesives show promise of higher top speeds based on data from the double backer simulator. These will be tested in the pilot plant shortly.

Washboarding and warp are both strong functions of the amount of adhesive applied as well as the solids fraction in the adhesive. Deficiencies in the metering systems employed in the pilot system have been discussed elsewhere but the basic difficulty is over application of adhesive and poor control of application rate. This contributes to washboarding, warp and moisture content in the combined board. All three characteristics are expected to be improved substantially by using higher solids level adhesives and appropriate metering systems. These tools, plus appropriate web tension and moisture controls in a commercial machine, should lead to the production of flat, dry board with little washboarding. The cost of achieving these ends in the pilot system is not justified, however, and thus the production of board of optimal quality must await operation of the first machine designed specifically to meet the requirements of the cold process.

For illustration of other combined board performance characteristics, data from two test runs, one conducted on October 22, 1978, and the other on January 28, 1979, are presented in Tables VII and VIII, respectively. For the October 22 test, Table VII, a relatively high viscosity adhesive was used. This adhesive was also somewhat unstable because of the presence, in the finished adhesive, of some uncooked starch which continued to degrade in the hot alkaline environment of the holding system. Despite these difficulties, which have since been corrected, this particular adhesive gave the best production speed performance on the double backer of any adhesive tested on the pilot system.

This test was conducted with 42 lb/M ft² kraft liners and a 26 lb/M ft², 50% OCC medium. Salient results from this test are as follows:

- a. Combined board of good quality was produced at double backer speeds of 500 fpm with a totally cold double face liner (Column A2).
- b. Top production speeds of 650 fpm were achieved with liner preheating (Column A4).
- c. All board and box properties except flat crush are equal to or better than those for board produced from the same components utilizing the hot process.
- d. Flat crush values are low partially for the reasons discussed earlier with respect to single face board flat crush values and partly because of flute distortion caused by drag in the simply converted double backer section.

TABLE VII

COMPONENT, BOARD, AND BOX DATA FROM PILOT TRIALS

SF Liner: 42 lb/M ft² kraft
Medium: 26 lb/M ft² NSSC - 40% OCC
DF Liner: 42 lb/M ft² kraft

October 22, 1978

Test A

Component Properties

Basis weight	SF liner	41.2
	Medium	27.4
	DF liner	41.2
Caliper	SF liner	12.6
	Medium	12.3
	DF liner	12.6
Medium water drop		45
Cobb size	SF liner	31.6
	DF liner	31.6
CD ring crush	SF liner	12.6
	Medium	6.1
	DF liner	12.6
Mullen	SF liner	97
	DF liner	97

Operating Conditions

	A1	A2	A3	A4
SF speed	200	200	200	200
DF speed	300	500	400	650
Liner preheat	No	No	Yes	Yes

Board Properties

CB caliper	170	171	169	169
Pin adhesion	SF	122	111	105
	DF	104	99	103
Burst	238	230	228	227
Puncture	190	188	190	187
Edgewise compression	39.9	38.0	37.6	37.2
CB flat crush	23.3	23.5	23.8	25.0

Box Properties

Top-to-bottom compression	760	720	710	700
Deflection	0.57	0.56	0.54	0.56

TABLE VIII

COMPONENT, BOARD, AND BOX DATA FROM PILOT TRIALS

SF Liner: Test B and C - 42 lb/M ft² kraft
Test D - 69 lb/M ft² kraft
Medium: 26 lb/M ft² NSSC - 40% OCC
DF Liner: Test B - 42 lb/M ft² bleached kraft
Test C and D - 42 lb/M ft² kraft

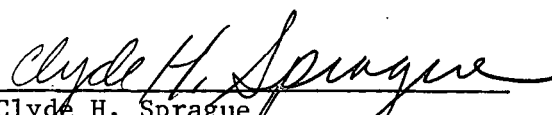
<u>Component Properties</u>		January 28, 1979					
		B	C		D		
Basis weight	SF liner	43.5	43.5		69.0		
	Medium	27.4	27.4		27.4		
	DF liner	40.4	43.0		43.0		
Caliper	SF liner	12.6	12.6		--		
	Medium	11.3	11.3		11.3		
	DF liner	10.2	12.4		12.4		
Medium water drop							
Cobb size	SF liner	39.7	39.7				
	DF liner	32.2	43.2		43.2		
CD ring crush	SF liner	15.3	15.3				
	Medium	6.0	6.0				
	DF liner	14.2	15.8		15.8		
Mullen	SF liner	97	97				
	DF liner	91	106		106		
<u>Operating Conditions</u>		B1	B2	C1	C2	D1	D2
SF speed		200	200	200	200	200	200
DF speed		200	400	300	400	200	500
Liner preheat		No	No	No	No	Yes	Yes
<u>Board Properties</u>							
CB caliper		167	166	168	169	171	172
Pin adhesion	SF	113	115	126	118	135	130
	DF	111	123	124	122	137	132
Burst			218		254	295	298
Puncture		198		204		261	
Edgewise compression		45.6	44.4	49.3	47.7	61.2	60.0
CB flat crush		24.2	24.2	26.3	26.1	26.4	25.4
<u>Box Properties</u>							
Top-to-bottom compression		850	840	910	820	1140	1170
Deflection		0.56	0.49	0.51	0.49	0.81	0.68

For the test conducted on January 28, a stable, lower viscosity adhesive was used. Corresponding data are shown in Table VIII. Test B was conducted with a bleached kraft liner on the DF side; Test C with a 42 lb/M ft² kraft liner on both sides; Test D with a 69 lb/M ft² kraft liner on the SF side and a 42 lb/M ft² kraft liner on the DF side. This particular adhesive has a lower production speed limit than that used in the October 22 test. Otherwise the comments above are applicable. Particular attention is called to the box compression results from Tests B and C which show exceptionally high top-to-bottom strength.

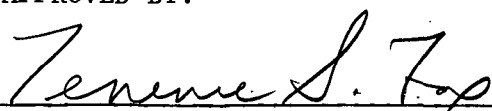
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